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A

MANUAL OF PHYSIOLOGY,

INCLUDING

PHYSIOLOGICAL ANATOMY.

By the same Author.

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A MANUAL

OF

PHYSIOLOGY,

INCLUDING

PHYSIOLOGICAL ANATOMY.

BY

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PREFACE.

THE present volume owes its origin to a desire on the part of the Publisher, that an elementary treatise on Physiology should be added to the series of admirable Students' Manuals, on the various departments of Medical Science, which he had previously issued.

In carrying this desire into execution, the Author has endeavoured to avoid inflicting upon the class for whose use the Treatise is especially intended, the injury of placing in their hands such a superficial and imperfect sketch of the science, as, whilst affording them but a limited amount of knowledge of its facts, should leave them very ill-informed as to its general doctrines. His object has rather been to convey to the Student as clear an idea as possible of those Principles of Physiology which are based on the broadest and most satisfactory foundation, and to point-out the mode in which these principles are applied to the explanation of the phenomena presented by the living actions of the Human body. In this manner has the Author desired to prepare him for that more detailed study of the latter, which becomes necessary when Physiology is pursued (as it ought to be) in connection with the changes produced in the living body by Morbific and Remedial Agents, and is thus taken as a guide in the study of the causes, prevention, and treatment of Disease—which should be the primary object of attention with every one who undertakes the Practice of his Profession.

Although this Manual combines in some degree the scope of the Author's "Principles of General Physiology," "Principles of Comparative Physiology," and "Principles of Human

Physiology," yet it cannot be regarded as a mere abridgment of them, having been written for the most part with very little reference to them, and with every desire to make it complete in itself. As the matter of which these volumes are composed is itself condensed to the utmost practicable degree, it is manifestly impossible that the present Manual should contain more than a mere outline of the subjects of which they treat. To them, therefore, he would refer such of its readers as may desire further information upon various topics which are here only slightly touched-upon; and in them, also, will be found references to various original authorities, the introduction of which would be incompatible with the limited scope of a treatise like the present.

The Author has only to add, that he feels most grateful for the kind appreciation which this Manual has experienced; and that, in the preparation of the present Edition, he has used his best endeavours to render it still more worthy of a favourable reception. The whole treatise has been subjected to a most careful revision; a few statements which the advance of science has shown to be doubtful or erroneous, have been omitted or corrected; and a considerable amount of new matter has been introduced. Twenty-five new Wood-engravings of first-rate excellence, selected from Prof. Ecker's beautiful "Icones Physiologicæ," have been introduced; fifteen of these being additions to the previous total, whilst ten take the place of subjects which it was not thought desirable to retain.

University Hall, London,
Aug. 1, 1856.

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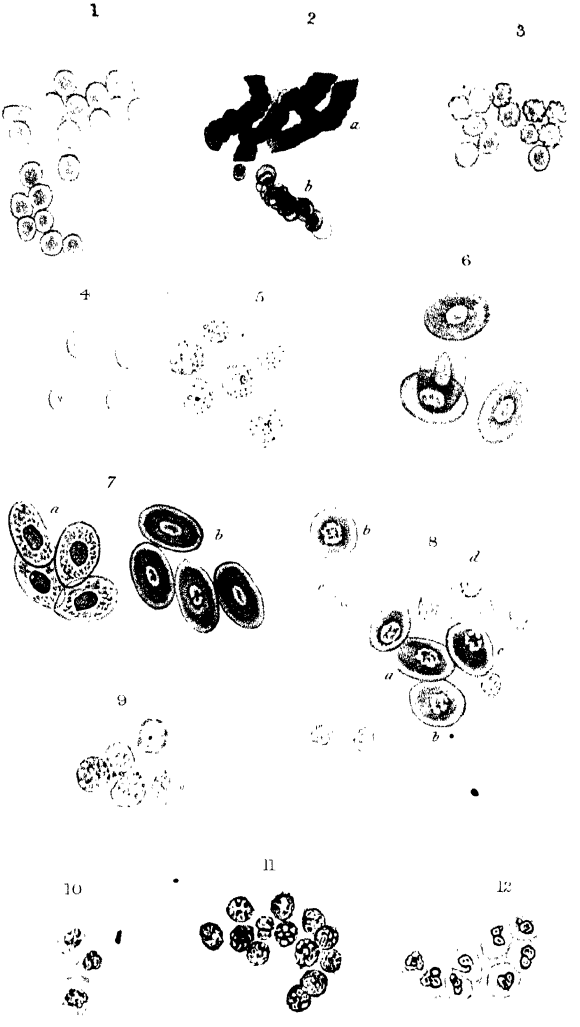
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EXPLANATION OF PLATE I.

The Figures in this Plate represent the Cells floating in the various animal fluids; and they are all, with the exception of Figs. 4 and 5, copied from the representations given by M. Donné in his "Atlas de l'Anatomie Microscopique." These representations are transcripts of Daguerreotype pictures, obtained from the objects, by a solar microscope, with a magnifying power of 400 diameters.

Fig. 1. Red Corpuscles of Human Blood, viewed by their flattened surfaces (§ 215).

Fig. 2. Red Corpuscles of Human Blood, adherent by their flattened surfaces, so as to form rolls;—at *a*, the entire surfaces are adherent; at *b*, their surfaces adhere only in part.

Fig. 3. Red Corpuscles of Human Blood, exhibiting the granulated appearance which they frequently present, a short time after being withdrawn from the vessels.

Fig. 4. Colourless Corpuscles of Human Blood (§ 214).

Fig. 5. The same, enlarged by imbibition of water.

Fig. 6. Red Corpuscles of Frog's Blood (§ 215).

Fig. 7. The same, treated with dilute acetic acid; the first effect of which is to render the nucleus more distinct, as at *b*: after which the outer vesicle becomes more transparent, and its solution commences, as at *a*.

Fig. 8. The same, treated with water; at *a* is seen a corpuscle nearly unaltered, except in having the nucleus more sharply defined; at *b*, others which have become more spherical, under the more prolonged action of water; at *c*, the nucleus is quitting the centre and approaching the circumference of the disk; at *d* it is almost freeing itself from the envelope; and at *e* it has completely escaped.

Fig. 9. Globules of Mucus, newly secreted (§ 237).

Fig. 10. The same, acted-on by acetic acid.

Fig. 11. Globules of Pus, from a phlegmonous abscess (§ 637).

Fig. 12. The same, acted-on by acetic acid.

EXPLANATION OF PLATE II.

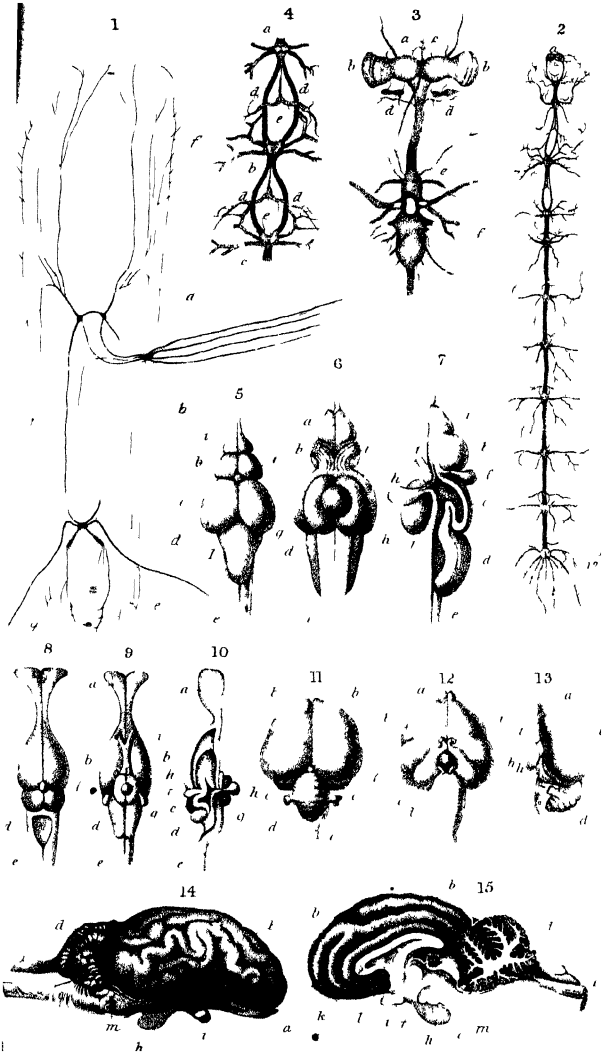
The Figures in this Plate represent the principal forms of the Nervous Centres in different classes of animals. The first is copied from a Memoir by M. Blanchard; the 2nd, 3rd, and 4th, from Mr. Newport's delineations; the 5th to the 13th from the work of M. Guillot on the Comparative Anatomy of the Encephalon in the different classes of Vertebrata; and the last two from the work of M. Leuret on the same subject.

Fig. 1. Nervous System of *Solen*; *a*, *a*, cephalic ganglia, connected together by a transverse band passing over the Œsophagus, and connected with the other ganglia by cords of communication; *b*, pedal ganglion, the branches of which are distributed to the powerful muscular foot; *c*, branchial ganglion, the branches of which proceed to the gills *d*, *d*, the siphons *e*, *e*, and other parts. On some of these branches, minute ganglia are seen; as also at *f*, *f*, on the trunks that pass forwards from the cephalic ganglia (§ 852).

Fig. 2. Nervous System of the *Larva* of *Sphinx ligustri*; *a*, cephalic ganglia; 1—12, ganglia of the ventral cord (§ 856).

Fig. 3. Thoracic portion of the Nervous System of the *Pupa* of *Sphinx ligustri*; *a*, *b*, *c*, three ganglia of the ventral cord; *d*, *d*, their connecting trunks; *e*, *e*, respiratory ganglia (§ 862).

Fig. 4. Anterior portion of the Nervous System of the *Imago* of *Sphinx ligustri*; *a*, cephalic ganglia; *b*, *b*, eyes; *c*, anterior median ganglion, and *d*, *d*, posterior lateral ganglia of stomato-gastric system; *e*, *f*, large ganglionic masses in the thorax, giving origin to the nerves of the legs and wings (§ 863).


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BOOK I.

GENERAL PHYSIOLOGY.

CHAPTER I.

ON THE NATURE AND OBJECTS OF THE SCIENCE OF PHYSIOLOGY.

1. THE general distribution of the objects presented to us by external Nature, into three kingdoms—the Animal, the Vegetable, and the Mineral,—is familiar to every one; and not less familiar is the general distinction between living bodies, and inert matter. True it is, that we cannot always clearly assign the limits which separate these distinct classes of objects. Even the professed Naturalist is constantly subject to perplexity, as to the exact boundary between the Animal and the Vegetable kingdoms; and the distinction between Animal and Vegetable structures on the one hand, and Mineral masses on the other,—or between living bodies, and aggregations of inert matter,—is by no means so obvious in every case, as to be at once perceptible to the unscientific observer. Thus, a mass of Coral, if its growing portion be kept out of view, or a solid Nullipore attached to the surface of a rock, might be easily confounded with the mineral masses to which they bear so close a resemblance; and a minute examination might be required to detect the difference. Nevertheless, a well-marked distinction does exist, between the *organized* structures of Plants and Animals, and the *inorganic* aggregations of Mineral matter; as well as between the condition of a *living* being, whether Animal or Plant, and that of *dead* or *inert* Mineral bodies. It is upon these distinctions, which are usually obvious enough, that the sciences of ANATOMY and PHYSIOLOGY are founded; these sciences taking cognizance,—the former, of those structures which are termed *organized*,—and the latter, of the actions which are peculiar to those structures, and which are distinguished by the term *vital*. It will be desirable to consider, in a somewhat systematic order, the principal ideas which we attach to these terms; as we shall be thus led most directly to the distinct comprehension of the nature and objects of Physiological science.

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CHAPTER I.

ON THE NATURE AND OBJECTS OF THE SCIENCE OF PHYSIOLOGY.

1. THE general distribution of the objects presented to us by external Nature, into three kingdoms—the Animal, the Vegetable, and the Mineral,—is familiar to every one; and not less familiar is the general distinction between living bodies, and inert matter. True it is, that we cannot always clearly assign the limits which separate these distinct classes of objects. Even the professed Naturalist is constantly subject to perplexity, as to the exact boundary between the Animal and the Vegetable kingdoms; and the distinction between Animal and Vegetable structures on the one hand, and Mineral masses on the other,—or between living bodies, and aggregations of inert matter,—is by no means so obvious in every case, as to be at once perceptible to the unscientific observer. Thus, a mass of Coral, if its growing portion be kept out of view, or a solid Nullipore attached to the surface of a rock, might be easily confounded with the mineral masses to which they bear so close a resemblance; and a minute examination might be required to detect the difference. Nevertheless, a well-marked distinction does exist, between the *organized* structures of Plants and Animals, and the *inorganic* aggregations of Mineral matter; as well as between the condition of a *living* being, whether Animal or Plant, and that of *dead* or *inert* Mineral bodies. It is upon these distinctions, which are usually obvious enough, that the sciences of ANATOMY and PHYSIOLOGY are founded; these sciences taking cognizance,—the former, of those structures which are termed *organized*,—and the latter, of the actions which are peculiar to those structures, and which are distinguished by the term *vital*. It will be desirable to consider, in a somewhat systematic order, the principal ideas which we attach to these terms; as we shall be thus led most directly to the distinct comprehension of the nature and objects of Physiological science.

1. *General Characters of Organized Structures.*

2. Organized structures are characterized, in the first place, by the peculiarities of their *form.*—Wherever a definite form is exhibited by Mineral substances, it is bounded by straight lines and angles, and is the effect of the process termed *crystallization.* This process results from the tendency which evidently exists in particles of matter, especially when passing gradually from the fluid to the solid state, to arrange themselves in a regular and conformable manner in regard to one another. There is, perhaps, no inorganic element or combination, which is not capable of assuming such a form, if placed in circumstances adapted to the manifestation of this tendency among its particles; but if these conditions should be wanting, so that simple cohesive attraction is exercised in bringing them together, without any general control over their direction, an indefinite or shapeless figure is the result.—Neither of these conditions finds a parallel in the Organized creation. From the highest to the lowest, we find the shape presenting a determinate character for each *species* or *race*, with a certain limited amount of variation amongst *individuals;* and this shape is such, that, instead of being circumscribed within plane surfaces, straight lines, and angles, organized bodies are bounded by convex surfaces, and present rounded outlines. We may usually gather, moreover, from their external form, that they are composed of a number of dissimilar parts, or *organs;* which are combined together in the one individual body, and are characteristic of it. Thus in the Vertebrated or Articulated animal, we at once distinguish the head and extremities from the trunk, which constitutes the principal mass; and where there exist no external organs of such distinctness, as in some Mollusks, the rounded character of the general form is sufficiently characteristic. The very simplest grades of animal and vegetable life present themselves under a shape, which approaches more or less closely to the globular. It is among the lower tribes of both kingdoms that we find the greatest tendency to irregular departures from the typical form of the species; and thus is presented an approach, on the one hand, to that indefiniteness which is characteristic of non-crystalline mineral masses; and, on the other, to that variety of crystalline forms which the same mineral body may present, according to the circumstances which influence its crystallization.

3. With regard to *size*, again, nearly the same remarks apply. The magnitude of Inorganic masses is entirely indeterminate, being altogether dependent upon the number of particles which can be brought together to constitute them. On the other hand, the size of Organized structures is restrained, like their form, within tolerably definite limits, which may nevertheless vary to a certain extent

among the individuals of the same species. These limits are least obvious in Vegetables, and in the lower classes of Animals. A forest-tree may go on extending itself to an almost indefinite extent; certain species of sea-weed attain a length of many hundred feet, and their growth does not appear to be restrained by any limit; and the same may be said of those enormous masses of coral, which compose so many islands and reefs in the Polynesian Archipelago, or of which the *débris* seem to have constituted most of the calcareous rocks of ancient formation. But in these cases, the increase is produced by the multiplication of similar parts, which, when once completely evolved, have but little dependence one upon another, and might be almost considered as distinct individuals. Thus, each bud of a tree, if placed under favourable circumstances, can maintain its life by itself, and can perform all the actions proper to the species. Each polype of the coral mass, in like manner, at first produced by a process of budding from the original stock, comes in time to be completely independent both of it and of those with which it is associated. And in the sea-weed, each portion of the frond is an almost precise repetition of every other, and grows for and by itself; neither receiving from, nor communicating to, any other part, the materials of its organic structure. Thus among Plants and the lower Animals, we find an indefiniteness in point of size, depending upon the tendency to multiplication of similar parts, which has been designated as *vegetative* repetition.

4. It is, however, in the internal arrangement or aggregation of the particles, of which Organized structures and Inorganic masses are respectively composed, that we find the difference between the two most strongly marked.—Every particle of a Mineral body (in which there has not been a *mixture* of ingredients) exhibits the same properties as those possessed by the whole; so that the chemist, in experimenting with any substance, cares not, except as a matter of convenience merely, whether a grain or a ton be the subject of his researches. The minutest atom of carbonate of lime, for instance, has all the properties of a crystal of this substance, were it as large as a mountain. Hence we are to regard a mineral body as made-up of an indefinite number of constituent particles, similar to it and to each other in properties, and having no further relation among themselves, than that which they derive from their juxta-position. *Each particle*, then, may be considered as possessing a *separate individuality*; since we can predicate of its properties all that can be said of the largest mass. The Organized structure, on the other hand, receives its designation from being made-up of a number of distinct parts or *organs*, each of which has a texture and consistence peculiar to itself; and it derives its character from the whole of these collectively. Every one of them, as we shall hereafter see, is the instrument of a certain action or *function*, which it per-

forms under certain conditions; and the concurrence of all these actions is required for the maintenance of the structure in its normal or regular state, and for the prevention or the reparation of those changes, which chemical and physical forces would otherwise speedily produce in it, from causes hereafter to be explained. Hence there is a relation of *mutual dependence* among the parts of an Organized structure, which is quite distinct from that of mere proximity. The perfect Plant, which has roots, stem, leaves, and flowers, is an example of an organized structure, in which the relation of the different parts to the integrity of the whole is sufficiently obvious; since, when entirely deprived of either set of these organs, the race must perish, unless the plant have within itself the power of reproducing them.

5. It is not only in Zoophytes and other *aggregate* Animals, that we notice the tendency to 'vegetative repetition;' for it may be observed in many animals which cannot be divided without the destruction of their lives,—especially among the Radiated and the lower Articulated tribes. Where such a repetition exists, *some* of the organs may be removed without permanent injury to the structure; their function being performed by those that remain. Thus, it is not uncommon to meet with specimens of the common five-rayed Starfish, in which not only one or two of the 'arms' but even three or four, have been lost without the destruction of the animal's life; and this is the more remarkable, as the arms are not simply organs of locomotion or prehension, but are really divisions of the body containing prolongations of the stomach. In the bodies of the higher animals, however, where there are few or no such repetitions (save on the two sides of the body), and where there is consequently a greater diversity in character and function between the different organs, the mutual dependence of their actions upon one another is much greater, and the loss of a single part is much more likely to endanger the existence of the whole. Such structures are said to be more *highly-organized* than those of the lower classes; not because the whole number of parts is greater, for it is frequently much less; but because the number of *dissimilar* parts, and the consequent adaptation to a *variety* of purposes, is much greater,—the principle of 'division of labour,' in fact, being carried much further, a much greater variety of objects being attained, and a much higher perfection in the accomplishment of them being thus provided-for.

6. Keeping in view, then, what has just been stated in regard to the divisibility of a Tree or a Zoophyte into a number of parts, each capable of maintaining its own existence, we may trace a certain gradation from the condition of the Mineral body to that of the highest Animal, in regard to the character in question. Using the term individuality as a convenient expression for the capacity for independent existence, it may be said that the *individuality* of

A Mineral substance resides in each molecule; that of a Plant or Zoophyte, in each complete member; and that of one of the higher Animals, in the sum of all the organs.—The distinction is much greater, however, between the lowest Organized fabric and *any* Mineral body, than it is between the highest and the lowest organized structures: for, as we shall hereafter see, the highest and most complicated may be regarded as made-up of an assemblage of parts corresponding to the lowest and simplest; whose structure and actions have been so modified as to render them mutually dependent; but which yet retain a power of independent action, which enables them to continue performing their functions when separated from the mass, so long as the proper conditions are supplied.

7. Between the very simplest Organized fabric, and every form of Mineral matter, there is a marked difference in regard to *intimate structure* and *consistence*. Inorganic substances can scarcely be regarded as possessing a structure; since (if there be no admixture of components) they are uniform and *homogeneous* throughout, whether existing in the solid, the liquid, or the gaseous form; being composed of similar particles, held-together by attractions which affect all alike. Far different is the character of Organized structures; for in the minutest parts of these may be detected a *heterogeneous* composition,—a mixture of solid and fluid elements, which are so intimately combined and arranged, as to impart such peculiarities to the tissues, even in regard to their physical properties, as we never encounter amongst Mineral bodies. In the latter, *solidity* or *hardness* may be looked-upon as the characteristic condition; whilst in Organized structures, *softness* (resulting from the large proportion of fluid components) may be considered the distinctive quality, being most obvious in the parts that are most actively concerned in vital operations. This softness is evidently connected with the roundness of form characteristic of Organized fabrics, which is most evident when the tissues contain the greatest proportion of fluid; whilst the plane surfaces and angular contours of Mineral bodies are evidently due to the mode in which the solid particles are aggregated-together, without any intervening spaces.

8. The greatest solidity exhibited by Organized fabrics, is found where it is desired to impart to them the simple physical property of *resistance;* and this is attained by the deposition of solid particles, often of a mineral character, in tissues that were originally soft and yielding. It is in this manner that the almost jelly-like substance, in which all the organs of animals originate, becomes condensed into cartilage, and that the cartilage is afterwards replaced by bone; it is in the same manner, also, that the stones of fruit, and the heart-wood of timber-trees, are formed out of softer tissues. But, as we shall hereafter see, this kind of

conversion, whilst it renders the tissue more solid and durable, cuts it off from active participation in the vital operations; and thus reduces it to a state much more nearly analogous to that of mineral bodies. This resemblance is rendered more close by the fact, that the earthy deposits frequently retain a distinctly crystalline condition; so that, when they are present in large proportion, they impart a more or less crystalline aspect to the mass, and especially a crystalline mode of fracture, which is evident enough in many shells. It must not be hence concluded, however, that such substances are of an inorganic nature; all that is shown by their crystalline structure being, that the animal basis exists in comparatively small amount, and that the mode in which the mineral matter was deposited has not interfered with its crystalline aggregation.

9. It is not to be disputed that a certain degree of homogeneity is apparently to be found in the *minutest* elements, into which certain Organized tissues are to be resolved. Thus, in the *membranes* which form the walls of Animal and Vegetable cells, the highest powers of the microscope fail in detecting any such distinction of fluid and solid components, as that which has been described as characteristic of organized structures. Nevertheless it is indubitable that such distinct components *must* exist; and this especially from the properties of these membranes in regard to water. For it is one of the most remarkable facts in the whole range of science, that a membrane, in which not the slightest appearance of a pore can be discovered under the highest powers of the microscope, should be capable of allowing water to pass through it; and that, too, with no inconsiderable rapidity. The change which these membranes undergo in drying, is another proof that they are not so homogeneous as they appear, and that water is an element of their structure, not merely chemically, but mechanically. The same may be said in regard to the *fibres*, which form the apparently-ultimate elements of the simple fibrous tissues in Animals, and which are also met-with in the interior of certain cells and vessels in Plants. These fibres would appear to be of perfectly simple structure; yet we know from the loss of fluid and the change of properties which they undergo in drying, that water must have formed part of their substance.—It may be remarked, however, in regard to both these elementary forms of Organized tissue, that the simplicity of their function is in complete conformity with the apparent homogeneousness of their structure; for the cell-membrane is chiefly destined to act, like the porous septum in certain forms of the voltaic battery, as a boundary-wall to the contained fluid, without altogether interfering with its passage elsewhere; the forces which produce its imbibition or expulsion being probably situated, not in this pervious wall, but in the cavity which it bounds. And, in the same manner, the function of the fibrous

tissues, to which allusion was just-now made, is of an entirely-physical character; being simply to resist strain or tension, and yet to allow of a certain degree of yielding by their elasticity.

10. In all cases in which active Vital operations are going-on, we can make a very obvious distinction of the structures subservient to them, into liquid and solid parts; and it is, indeed, by the continual reaction which is taking-place between these, that the fabric is maintained in its normal condition. For, as we shall hereafter see, it is liable to a constant decomposition or separation into its ultimate elements; and it is consequently necessary that the matters which have undergone that disintegration should be carried-off, and that they should be replaced by new particles. These processes of removal and replacement, with the various actions subservient to them, make-up a large proportion of the life of every Organized being. Now as all the alimentary matter must be reduced to the liquid form, in order that it may be conveyed to the situations in which it is required, and as all the decomposed or disintegrated matter must be reduced to the same form in order to be carried-off, the intermingling or mutual penetration of solids and liquids in the minutest parts of the body is at once accounted-for. We shall hereafter see that a *cell*, or closed vesicle, formed of a membranous wall, and containing fluid, may be regarded as the simplest form of a living body, and the simplest independent part or instrument of the more complex fabrics (§ 21).

11. Organized structures are further distinguished from Inorganic masses, by the peculiarity of their *chemical constitution*. This peculiarity does not consist, however, in the presence of any elementary substances which are not found elsewhere; for all the elements of which organized bodies are composed, exist abundantly in the world around. It might have been supposed that beings endowed with such remarkable powers as those of Animals and Plants,—powers which depend, as we shall hereafter see, upon the exercise of properties to which we find nothing analogous in the Mineral world,—would have had an entirely different material constitution; but a little reflection will show, that the identity of the ultimate elements of Organized structures with those of the Inorganic world, is a necessary consequence of the mode in which the former are built-up. For that which the parent communicates in giving origin to a new being, is not the structure itself, but the capacity to form that structure from the surrounding elements; and it is by gradually drawing to itself certain of these elements, that the germ becomes developed into the complete fabric. Now, of the *sixty-five* simple or elementary substances, which are known to occur in the Mineral world, only about *eighteen* or *nineteen* are found in Plants and Animals; and many of these in extremely minute proportion. Some of these appear to be introduced, merely to answer certain chemical or mechanical purposes; and the com-

position of the parts which possess the highest vital endowments, is for the most part simpler and more uniform.

12. The actual *tissues* of Plants, when entirely freed from the substances they may contain, have been found to possess a very uniform composition, and to agree in their chemical properties. The substance which forms the principal part of the thickness of the walls of the cells, vessels, &c., of which the Vegetable organism is composed, is identical with *Starch* in the proportions of its components; but as these are in a different state of aggregation, it is distinguished as *Cellulose*. It consists of 12 Carbon, 10 Hydrogen, and 10 Oxygen; or, in other words, of Carbon united to the elements of Water, in the proportion of six of the former to five of the latter. It may be very easily converted into gum or sugar by Chemical processes, which effect the removal or the addition of the elements of water. Now there is no compound known to exist in the Inorganic world, which bears the remotest analogy to this; and we have no reason to believe that it could be produced in any other way, than by that peculiar combination of forces which exists in the growing Plant.—But although Cellulose is the predominating component of the Vegetable fabric, yet it is not the most essential; for within what has been ordinarily considered as the cell-wall, is a delicate membrane, termed the 'primordial utricle,' which is really the original cell-wall, from the exterior of which the cellulose-envelope is secreted;* and this is lined (at least in the active condition of the cell) by a layer of 'protoplasm,' a viscid liquid which is the formative material of all vegetable tissue; and both the one and the other contain an *albuminous* compound, in which the formative power seems especially to inhere. Hence every act of Vegetable growth involves the production of this substance also, which is still more removed in its composition from ordinary Inorganic compounds.

13. The composition of the Animal tissues, when freed from the solid matters which may have been deposited within them, is nearly as uniform. The chief material of the 'blastema' or formative liquid at whose expense they are all developed, and the fundamental constituent of all such as agree with the Vegetable tissues in their *cellular* character, is *Albumen;* which is composed of 40 Carbon, 31 Hydrogen, 5 Nitrogen, and 12 Oxygen, with a minute proportion of Sulphur and Phosphorus. But those *simple fibrous* tissues having none but a purely mechanical function, of which a large part of the fabric of the higher Animals is made-up, have as their basis the substance termed *Gelatine;* which consists of 13 Carbon, 10 Hydrogen, 2 Nitrogen, and 5 Oxygen. There is ample evidence that the gelatinous tissues derive their material from the albuminous 'blastema' which serves as the pabulum to the rest; but

* The 'primordial utricle' may probably be considered as the external layer of the protoplasm that invests the other cell-contents, which has undergone a certain degree of consolidation.

although albumen can be converted into gelatine in the living body, gelatine cannot be converted into albumen, so that it is quite incapable of affording nourishment to albuminous tissues, or even of contributing towards the formation of the organizable blastema.

14. As we shall hereafter dwell more in detail upon the Chemical Constitution of the Animal tissues and products (CHAP. III.), these substances are only noticed here, in illustration of the general statement, that the 'proximate principles' of Animal and Vegetable bodies (that is, the simplest forms to which their component structures can be reduced, without altogether separating them into their ultimate elements) are of extremely peculiar constitution; being made-up of three or four elements, of which the atoms do not seem to be united two by two, or by the method of *binary* composition, but of which a large number are brought-together to form one *compound atom*, of *ternary* or *quaternary* composition. This compound atom, like Cyanogen, and many others derived from Organic products, acts like a simple or elementary one in its combinations with other substances.—It is worthy of remark, however, that, in this respect as in others, the Vegetable kingdom is intermediate between the Animal and the Mineral. For whilst Albumen and Gelatine are remarkable, not only for containing *four* elements, but for the very large number of atoms of their components which enter into the single compound atom of each, the Cellulose of Plants is much simpler in its composition, since it includes only *three* elements, and the numbers which represent their proportions are smaller. And further, the proportions of the components of Cellulose are themselves such, as suggest the idea of simplicity in their method of combination,—the union of water and carbon in the common binary method;—an idea which is confirmed by the mode of its original production, which indicates a direct union of carbon with water; as well as by the fact, that the chemical difference between cellulose and numerous other substances found in Plants, may be represented by the simple addition or subtraction of a certain number of atoms of water, and that the chemist can effect an actual conversion of the former into certain of the latter, by means which are calculated to effect such an addition or subtraction.

15. We shall hereafter see that Vegetables are intermediate between the Animal kingdom and the Inorganic world in another most important particular—the nature of the Chemical operations they effect; for it is their function to combine the oxygen, hydrogen, carbon, and nitrogen, of the Inorganic world, into Organic Compounds; which not only serve as the materials of their own growth, but also as the food of Animals, whose existence is entirely dependent upon them, since *they* possess no such combining power. It is from the Water, Carbonic acid, and Ammonia, supplied by the atmosphere and by the soil in which they are fixed, that Plants derive these elements. On the other hand, the Animal, making

use of the ternary and quaternary compounds which have been elaborated by Plants, is continually breaking-up these compounds, and restoring their components to the Inorganic world, in the very forms which they originally possessed; for, as we shall hereafter see, the excretion of Water, Carbonic acid, and Ammonia is constantly taking-place in the living Animal body, as the result of those changes in which its peculiar activity consists; whilst these same binary compounds are set-free (with others) during the decomposition of the same body after its death. And thus is sustained that balance between Animal and Vegetable nutrition, which is found to be the more wonderful and complete, the more carefully it is scrutinized.

2. *Distinctive Characters of Vital Actions.*

16. We are now arrived at the second head of our inquiry,—namely, the nature of those *actions* which distinguish living beings from masses of inert matter, and which are designated as *Vital*, to mark their distinctness from Physical and Chemical phenomena. There can be no doubt whatever, that, of the many changes which take place during the *life*, or state of *vital activity*, of an Organized being, and which intervene between its first development and its final decay, a large proportion are effected by the direct agency of those forces which operate in the Inorganic world; and there is no necessity whatever for the supposition, that these forces have any other operation *in* the living body, than they would have *out* of it under similar circumstances. Thus the propulsion of the blood by the heart through the large vessels, is a phenomenon precisely analogous to the propulsion of any other liquid through a system of pipes by means of a forcing pump; and if the arrangement of the tubes, the elasticity of their walls, the contractile power of the heart, and the physical properties of the fluid, could be precisely imitated, the artificial apparatus would give us an exact representation of the actions of the real one. The motor force of the muscles upon the bones, again, operates in a mode that might be precisely represented by an arrangement of cords and levers; the peculiarity here, as in the former case, being solely in the mode in which the force is first generated. So, again, the digestive operations which take-place in the stomach are capable of being closely imitated in the laboratory of the chemist; when the same solvent fluid is employed, and the same agencies of heat, motion, &c., are brought into play. Moreover we shall hereafter see reason to believe, that the peculiar form of capillary attraction, to which the term 'endosmose' is applied, performs an important part in the changes which are continually occurring in the living body.

17. But after every possible allowance has been made for the operation of Physical and Chemical forces in the living Organism, there still remain a large number of phenomena, which cannot be

in the least explained by them, and which we can only investigate with success, when we regard them as resulting from the agency of forces as distinct from those of Physics and Chemistry, as *they* are from each other. It is to these phenomena that we give the name of *Vital;* the forces from whose operation we assume them to result, are termed *vital forces;* and the properties which we must attribute to the substances manifesting those forces, are termed *vital properties.* Thus we say that the *act of contraction* in a muscle is a *vital phenomenon,* because its character appears totally distinct from that of a Physical or Chemical action, and because it is dependent upon other vital changes in the muscular substance. The act is the manifestation of a certain *force,* the possession of which is peculiar to the muscular structure, and which is named the *Contractile force.* But that force is only exerted under certain conditions, and these may only recur at long intervals, though the capacity for exerting it may be always present in the organized tissue; this capacity is termed a *property;* and thus we regard it as the essential peculiarity of living Muscular tissue, that it possesses the vital property of *Contractility.* Or, to reverse the order, the muscle is said to possess the property of Contractility; the property, when the appropriate conditions are supplied, gives rise to the Contractile Force; and the Force produces, if its operation be unopposed, the act of Contraction.

18. It may be said that the distinction here made is a verbal one, and that a very simple thing is thus made complex; but it will be presently seen that it is necessary, in order to enable us to take correct views of the nature of Vital phenomena, and to understand their relations to those of the Inorganic world. And, in fact, the distinction between the *property,* the *force,* and the *action,* becomes apparent upon a little consideration. Of the 'property' we are altogether unconscious, so long as it is not called into exercise; we could not, for example, determine by the direct use of any of our senses, whether a certain piece of muscle retained, or had lost, its contractility. When the property is called into action by its appropriate stimulus, we may convince ourselves that a 'force' is generated, even if no sensible action is presented: thus, if we were to hold the two extremities of a muscle so firmly, as to prevent them from approximating in the least degree when its contractility was excited, we should be conscious of a powerful force tending to draw our hands together; and we might measure the amount of that force, by mechanical means adapted to determine the weight it would sustain. And lastly, if no obstacle be interposed to the 'act' of contraction, it then becomes obvious to our senses, by the change in the shape of the muscle, and by the approximation of its two extremities, as well as of the bones to which they are attached.

19. It is hoped that the propriety of the distinct use of the terms

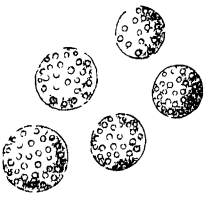
Vital Action, *Vital Force*, and *Vital Property*, will now be evident; and that the student will be prepared to attach distinct ideas to each of them. It is the business of the Physiologist to study those actions or phenomena which are peculiar to living beings, and which are hence termed *vital*:—he endeavours to trace them to the operation of specific forces acting through organized structures, just as the Astronomer traces all the movements, regular and perturbed, of the heavenly bodies, to the mutual attraction of their masses, acting concurrently with their force of onward rectilinear movement; or as the Chemist attributes the different acts of combination or separation, which it is his province to study, to the mutual affinities of the substances concerned:—and the physiologist, like the astronomer or the chemist, seeks to determine the *laws* according to which these forces operate, or, in other words, to express the precise conditions under which they are called into play, and the actions which they then produce. It is only in this manner, that Physiology can be rightly studied and brought to the level of other sciences. There can be no doubt that its progress has been greatly retarded by the assumption, that its phenomena were all to be attributed to the operation of some general controlling agency, or Vital Principle; and that the laws expressing the conditions of these phenomena, must be sought-for by methods of investigation entirely distinct from those which are employed in other sciences. But a better spirit is now abroad; and the student cannot be too strongly urged to discard any ideas of this kind, as absolutely untenable; and to keep steadfastly in view, that the laws of Vital Action are to be attained in the same manner as those of Physics or Chemistry,—that is, by the careful collection and comparison of vital phenomena, and by applying to them the same method of reasoning as that which is used in determining the forces and properties on which other phenomena depend. True it is, that we can scarcely yet hope to reach the same degree of simplification, as that of which other sciences are capable; but this merely results from the very complex nature of the phenomena themselves, and the difficulty of satisfactorily determining their conditions. The uncertainty of the results of Physiological experiments is almost proverbial: that uncertainty does not result, however, from any want of fixity in the conditions under which the vital forces operate, but merely from the influence of differences in those conditions, apparently so slight as to elude observation, and yet sufficiently powerful to produce an entire change in the result. And, owing to that mutual dependence of the several actions of the organized structure, to which reference has been already made (§ 5), we cannot seriously derange one class of these actions, without also deranging, or even suspending others;—a circumstance which obviously renders vital phenomena much more difficult of investigation than those of inorganic matter.

20. All sciences have their 'ultimate facts;' that is, facts for which no other cause can be assigned than the Will of the Creator. Thus, in Physics, we cannot ascend above the fact of Attraction (which operates according to a simple and universal law) between all masses of matter; and in Chemistry, we cannot rise beyond the fact of Affinity (limited by certain conditions which are not yet well understood) between the particles of different kinds of matter. When we say that we have *explained* any phenomenon, we merely imply that we have traced its origin to properties with which we were previously acquainted, and shown that it takes place in accordance with the known laws of their operation. Of the existence of the properties, and the determination of the conditions of their action, we can give no other account than that the Creator *willed* them so to be; and, in looking at the vast variety of phenomena to which they give rise, we cannot avoid being struck with the general harmony that exists amongst them, and the mutual dependence and adaptation that may be traced between them, when they are considered as portions of the general economy of Nature.—There is no difference in this respect between Physiology and other sciences; except that the number of these (apparently) ultimate facts is at present greater in physiology than it is elsewhere, because we are not yet able to include them all under any more general expression. But the march of discovery tends decidedly towards simplification; and its generalizations will be more sure, the wider the basis of facts on which they are founded, and the greater the caution exercised in erecting them.

21. In the study of any branch of science, it is most desirable to commence with definite views of the nature of the phenomena with which it is concerned; and such are best gained by the examination of these phenomena under their simplest aspects. This course is most especially necessary in Physiology; since the complexity of the conditions under which its phenomena usually present themselves, often tends to mask their real character, causing that to be regarded as essential which is only accidental or contingent, and *vice versâ*. It is extremely difficult, however, and frequently impossible, for the Physiologist to isolate these several conditions, and to study them separately, in the way that the Chemical or Physical investigator would do; and his best course is to take advantage of those "experiments ready prepared by Nature," which he finds in the variety of forms of living organized beings, with which this globe is so richly peopled. Now it is in the simplest forms of Cryptogamic Vegetation, that the phenomena of Life present themselves under their least complicated aspect; for we shall find in the operations of each of those simple cells of which such Plants are composed (all of them resembling one another in structure and actions), an *epitome*, as it were, of those of the highest and most complex Plant; whilst those of the higher Plants bear a close cor-

respondence with those which are immediately concerned in the Nutrition and Reproduction of the Animal body.—A *Cell*, then, in the language of Physiology, is a closed vesicle or minute bag, formed by a membrane in which no definite structure can be discerned, and having a cavity which may contain matters of variable consistence; but which possesses in itself the power of growth and (in its typical condition at least) of multiplication also. Such a cell constitutes the entire organism of such simple plants as the *Protococcus nivalis* ('red snow'), or *Palmella cruenta* ('gory dew'); for although the patches of this kind of vegetation which attract our notice, are made up of vast aggregations of such cells, yet they have no dependence one upon another, and the actions of each are an exact repetition of those of the rest. In such a cell, every organized fabric, however complex, originates. The vast *tree*, almost a forest in itself, and the feeling, thinking, intelligent *man*, spring from a germ, that differs in no obvious particular from the permanent condition of one of these lowly beings. But whilst the powers of the latter are restricted, as we shall see, to the continual multiplication of new and distinct individuals like itself, those of the former enable it to produce new cells that remain in closer connexion with each other; and these are gradually converted, by various transformations of their own, into the diversified elements of a complex fabric. The most highly-organized being, however, will be shown to consist in great part of cells that have undergone no such transformation, amongst which the different functions performed by the individual in the case just cited, are distributed, so to speak; so that each cell has its particular object in the general economy, whilst the history of its own life is essentially the same as if it were maintaining a separate existence.

Fig. 1.*



22. We shall now examine, then, the history of the solitary cell of one of the simplest Cryptogamic Plants, from its first development to its final decay; in other words, we shall note those Vital Phenomena, which are as distinct from those of any inorganic body, as is its organized structure (simple as it appears) from the mere aggregation of particles in a mineral mass.—In the first place, the cell takes its origin from a *germ*, which may be a minute *molecule*, that cannot be seen without a microscope of high power.† This

* Simple isolated cells, containing reproductive molecules.

† The modes in which new cells may be generated are various; but the above example is purposely drawn from one of those simple Algæ, whose usual mode of multiplication is by 'zoospores.' (See the Author's "Principles of Comparative Physiology," 4th Ed., §§ 351, 484, 486.)

molecule appears, in its earliest condition, to be a simple homogeneous particle, of spherical form; but it gradually increases in size; and a distinction becomes apparent between its transparent exterior and its coloured interior. Thus we have the first indication of the *cell-wall*, and the *cavity*. As the enlargement proceeds, the distinction becomes more obvious; the cell-wall is seen to be of extreme tenuity and perfectly transparent, and to be homogeneous in its texture; whilst the contents of the cavity are distinguished by their colour, which is very commonly either green or crimson. At first they, too, appear to be homogeneous; but a finely-granular appearance is then perceptible; and a change gradually takes place, which seems to consist in the aggregation of the minute granules into molecules of more distinguishable size and form. These molecules, which are the germs of new cells, seem to be at first attached to the wall of the parent-cell; afterwards they separate from it, and move-about in its cavity; and at a later period, the parent-cell bursts and sets them free. Now this is the termination of the life of the parent-cell, but the commencement of a life of a new brood; since every one of these germs may become developed into a cell, after precisely the foregoing manner, and will then in its turn multiply its kind by a similar process.

23. By reasoning upon the foregoing history, we may arrive at certain conclusions, which will be found equally applicable to all living beings. In the first place, the cell originates in a germ or reproductive body, which has been prepared by another similar cell that previously existed. There is no sufficient reason to believe that any exception to this rule exists; for so far as we at present know, every Plant and every Animal is the offspring of a parent, to which it bears a resemblance in all essential particulars. But how does this *germ*, this apparently homogeneous molecule, become a Cell? The answer to this is only to be found in its peculiar property of drawing materials to itself from the elements around, and of incorporating these with its own substance. The Vegetable cell may grow wherever it can obtain a supply of water, carbonic acid, and ammonia; for these compounds supply it with oxygen, hydrogen, carbon, and nitrogen, in the state most adapted for the exercise of its peculiar combining power, by which it converts them into those new compounds, whose properties adapt them to become part of the growing organized fabric. Here, then, we have two distinct operations;—the union of these elementary substances into the organic compounds which serve as the materials of the Vegetable tissues;—and the incorporation of those products with the substance of the germ itself. Starch, Cellulose, and Sugar all consist of Carbon united with the elements of Water; the proportion being 12 of the former to 10 of the latter in the case of the first two, and 12 of the former to 11 of the latter in the case of the third. Hence, as carbonic acid contains its own bulk of oxygen,

that element must be set-free, whenever Starch, Cellulose, or Sugar is formed by the union of the Carbon of carbonic acid with the elements of Water, in the process of vegetable growth. So it can be shown that when Vegetable Albumen is formed, at the expense of Water, Carbonic Acid, and Ammonia, there must be a disengagement of oxygen in the course of the re-arrangement of their elements which then takes-place. This result of the nutritive operations of the simple cellular plants may be easily verified experimentally, by exposing the green scum, which floats upon ponds, ditches, &c., and which consists of the cells of a minute Cryptogamic Plant, to the influence of light and warmth beneath a receiver; it is found that oxygen is then liberated by the decomposition of the carbonic acid contained in the water. We shall presently have to return to the consideration of the Chemical phenomena of living beings; and shall pass on. therefore, to consider those to which no such explanation applies.

24. The *first* of these changes *may be*, and probably *is*, of a purely *Chemical* nature; and analogous cases are not wanting, in the domain of Inorganic Chemistry, in which one body, A, exerts an influence upon two other bodies, B and C, so as to occasion their separation or their union, without itself undergoing any change. Thus platinum, in a finely-divided state, will cause the union of oxygen and hydrogen at ordinary temperatures; and finely-powdered glass will do the same at the temperature of 572°. This kind of action is called *catalysis*.—A closer resemblance, perhaps, is presented by the act of *fermentation;* in which a new arrangement of particles is brought-about in a certain compound, by the presence of another body which is itself undergoing change, but which does not communicate any of its elements to the new products. Thus, if a small portion of animal membrane, in a certain stage of decomposition, be placed in a solution of sugar, it will occasion a new arrangement of its elements, whereby two new products are generated, alcohol and carbonic acid. If the decomposition of the membrane have proceeded further, a different product will result; for instead of alcohol, lactic acid will be formed. And in a further stage of decomposition, the ferment is the means of producing butyric acid (the fatty acid of butter). There appears no improbability, then, in the idea, that the influence exerted by the germinal molecule is of an analogous nature; and that it operates upon the elements of the surrounding water and carbonic acid, according to purely Chemical laws, uniting the carbon with the elements of water, and setting-free the oxygen.

25. The *second* stage in the nutritive process, consists in the appropriation of the new products thus generated to the enlargement of the living cell-structure; a phenomenon obviously distinct from the preceding. It is well to observe, that this process, which constitutes the act of *Organization*, may be clearly distinguished in

the higher Plants and Animals, as consisting of two stages;—the first of these being that of *assimilation*, which consists in the further preparation or elaboration of the fluid matter, by certain alterations whose nature is not yet clear, so as to render it *plastic* or *organizable*;—the second being the act of *formation*, or the conversion of such organizable matter into the solid texture, in which process the properties that distinguish that texture come to manifest themselves. Thus, for example, we do not find that a solution of dextrin (or starch-gum) is capable of being at once applied to the development of Vegetable tissue, although it is identical in composition with cellulose; for it must be worked-up with albuminous matter into that peculiar glutinous substance termed *protoplasm*, which is present wherever cell-development is taking-place. And in like manner, the albumen of Animals does not seem capable of being applied to the formation of tissue, until it has been first converted into the organizable *blastema* (of which we have a specimen in the plastic exudation poured-out for the reparation of injuries), distinguished by its tenacious character, by its spontaneous coagulability, and by the fibrous structure of its clot.—Now, in both these cases, there is probably some slight modification in Chemical composition, that is, in the proportions of the ultimate elements; but the *principal* alteration is evidently that which is effected by the re-arrangement of the constituent particles; so that, without any considerable change in their proportions, a compound of a very different nature is generated. Of the possibility of such changes, we have abundant illustrations in ordinary Chemical phenomena; for there is a large class of substances, termed *isomeric*, which, with an identical composition, possess chemical and physical properties of a most diverse character.

26. But we cannot attribute the elaboration of the organizable from the unorganizable material, to the simple operation of the same agencies as those which determine the production of the different isomeric compounds; for (to take one of the most striking examples of this change) the properties of the Fibrin of a plastic exudation are much more *vitally* distinct from those of Albumen, than they are either *chemically* or *physically*; that is, we find in the one an incipient manifestation of *Life*, of which the other shows no indications. The spontaneous coagulation of fibrin, which takes place very soon after it has been withdrawn from the vessels of the living body, is a phenomenon to which nothing analogous can be found elsewhere; for it has been clearly shown not to be occasioned by any mere physical or chemical change in its constitution; and it occurs in a manner which indicates that a new arrangement of particles has been effected in it, preparatory to its being converted into a living solid. For this coagulation is not the mere homogeneous 'setting' which takes-place in a solution of gelatine in cooling; nor is it the aggregation of particles in a mere granular state (closely

resembling that of a chemical precipitate), which takes-place in the coagulation of albumen: it is the actual production of a simple *fibrous tissue*, by the union of the particles of fibrin in a determinate manner, bearing a close resemblance to the similar process in the living body (§ 193). We say, then, that the coagulation of Fibrin, and the production of a fibrous tissue, are the manifestation of its *vital* properties, rather than the direct result of chemical or physical agencies; because no substance is known to perform any such actions, without having been subjected to the influence of a living body; and because the actions themselves are altogether different from any which we witness elsewhere.

27. The act of Formation seems to consist of a continuation of the same kind of change,—that is, a new arrangement of the particles, producing substances which differ both as to structure and properties from the materials employed, but which may be so closely allied to them in chemical composition, that the difference cannot be detected. Thus, from the 'protoplasm' of the Plant are generated, in the process of the development of its cells, the various component parts of each of these integers:* chemically speaking, there seems to be no essential distinction between these substances; and yet between the living, growing, reproducing cell, and the gelatinous, semifluid matter in which they originate, how wide the difference! So in the Animal body, we find that the composition of the proper muscular tissue scarcely differs, in regard to the proportion of its elements, from the fibrin, or even from the albumen, of the blood; and yet what an entire re-arrangement must take-place in the particles of either, before a tissue so complex in structure, and so peculiar in properties, as muscular fibre, can be generated!

28. Both in the Plant and the Animal, moreover, we find that tissues presenting great diversities both in structure and properties, may take their origin in the same organizable material; but in every case (at least in the ordinary processes of growth and reparation) the new tissue of each kind is formed *in continuity* with that previously existing. Thus in the stem of a growing tree, from the very same glutinous sap or cambium intervening between the wood and the bark, the wood generates, in contact with its last-formed layer, a new cylinder of wood; whilst the bark produces, in contact with *its* last-formed layer, a new cylinder of bark; the woody cylinder being characterized by the predominance of ligneous fibre and ducts, and the cortical by the predominance of peculiar kinds of cellular tissue. In like manner we find that, in animals, muscle produces muscle, bone generates bone, nerve developes nerve, in continuity with itself, all at the expense of the materials supplied by the very same blood.

* For a carefully detailed history of this process, as observed in the first formation of the leaves of certain Plants, see Mr. Wenham's Memoir in the "Transactions of the Microscopical Society," New Series, vol. iv.

29. The *Nutrition* of tissues, by the organization of the materials contained in the nutrient fluid with which they are supplied, may be superficially compared, therefore, to the act of crystallization, when it takes-place in a mixed solution of two or more salts. If in such a solution we place small crystals of the salts it contains, these crystals will progressively increase by their attraction for the other particles of the same kind, which were previously dissolved; each crystal attracting the particles of its own salt, and exerting no influence over the rest. And it is curious that if either of the crystals be broken, the new deposit will take-place upon it in such a mode as gradually to reproduce its characteristic form. But it must be borne in mind, that such a resemblance goes no farther than the surface; for the growth of a crystal cannot be really regarded as in the least analogous to that of a cell. The crystal progressively increases by the deposit of particles upon its exterior; the interior undergoes no change; and whatever may be the size it ultimately attains, its properties remain precisely the same as those of the original nucleus. On the other hand, the cell grows from its original germ by a process of *interstitial* deposit; the substance of which its wall is composed, extends itself in every part; and the new matter is completely incorporated with the old.

30. Moreover, as the increase proceeds, we see an evident distinction between the cell-wall and its cavity; and we observe that the cavity is occupied by a peculiar matter, different from the substance of the cell-wall, though obviously introduced through it. Of the essential difference which may exist in composition, between the cell-wall and the contents of the cavity, we have a remarkable example in the case of the simple Cryptogamic plant that constitutes Yeast, which differs in no essential part of the history of its growth from the examples already referred to. The principal component of its cell-walls is nearly identical with ordinary cellulose; whilst the contents of the cells are closely allied in composition to proteine. Again, in the fat-cells of Animals, the cell-wall is formed from an albuminous compound; whilst the oily contents agree, in the absence of nitrogen, and in their general chemical relations, with the materials of the tissues of Plants. It is evident, then, that one of the inherent powers of the cell, is that by which it not only combines the surrounding materials into a substance adapted for the extension of its *wall*, but that which enables it to exercise a similar combining power on other materials derived from the same source, and to form a compound,—of an entirely different character, it may be,—which occupies its *cavity*. Now this process is as essential to our idea of a living cell, as is the growth of its wall; and it must never be left out of view, when considering the history of its development.

31. Every kind of cell has its own specific endowments; and generates in its interior a compound peculiar to itself. The nature

of this compound is much less dependent upon the nutrient materials which are supplied to the cell, than upon the original inherent powers of the cell itself, derived from its germ. Thus we find that the 'red snow' and 'gory dew' invariably form a peculiar red secretion; and that they will only grow where they can obtain, from the air and moisture around, the elements of that secretion. Again, the 'yeast-plant' invariably forms a secretion analogous to animal albumen; and it will only grow in a fluid which supplies it with the materials of that substance. Hence the 'red snow' would not grow in a fermentible saccharine fluid; nor would the 'yeast plant' vegetate on damp cold surfaces. Yet there is little difference, if any, between their cell-walls, in regard to chemical composition.—So, also, we shall find hereafter that one set of cells in the animal body will draw into themselves, during the process of growth, the elements of bile; another, the elements of milk; another, fatty matter; and so on: the peculiar endowments of each being derived from their several germs, which seem to have an attraction for these substances respectively, and which thus draw them together; whilst the cell-wall appears to have a uniform composition in all instances.

32. The term *Secretion* or setting apart, is commonly applied to this operation, to distinguish it from Nutrition or growth; but it is obvious from what has now been stated, that the act of secretion is in reality the increase or growth of the cell-contents, just as the process of enlargement is the increase or growth of the cell-wall; and that the two together make up the whole process of Nutrition, which cannot be properly understood, unless both are taken into account. It is to be remembered, however, that the *contents* of the cell may not be destined to undergo organization; indeed we shall find hereafter, that the main use of certain cells is to draw-off from the circulating fluid such materials as are incapable of organization; and the operation may be so far attributed, therefore, to the agency of Chemical forces. But we shall find that, in other instances, the cell-contents *are* destined to undergo organization, and this either within the parent-cell, or after they leave it; here, then, we must recognize a distinct vitalizing agency, as exerted by the cell upon its contents.

33. This organizing or vitalizing influence must be exerted upon a certain portion of the contents of every cell that is capable of reproducing itself; for it is in this manner that those germs are produced, in which all the wonderful properties are inherent, that are destined to manifest themselves, when they are set free from the parent-cell. This power of *Reproduction* is one of those which most remarkably distinguishes the living being; and we shall find that, in the highest Animal, as in the humblest Plant, it essentially consists in the preparation of a cell-germ, which, when set free, gradually developes itself into a structure like that from

which it sprang. The reproductive molecules or cell-germs are formed, like the tissue and the contents of the parent-cell, from the nutrient materials which it has the power of bringing together and combining; in their turn they pass through a corresponding series of changes; and at length they produce a new generation of similar molecules, by which the race is destined to be continued. Notwithstanding the mystery which has been supposed to attach itself to this process, it is obvious that there is nothing in reality more difficult to understand in the fact, that the parent-cell organizes and vitalizes the protoplasma which it has elaborated, so that it should form the germ of a *new* individual possessing similar properties with itself, than in its incorporating the same material with *its own* structure, and causing it to take a share in its own actions.

34. Finally, the parent-cell having arrived at its full development, having passed through the whole series of changes which is characteristic of the species, and having prepared the germs by which the race is to be propagated, *dies* and *decays*;—that is, all those operations, which distinguish living organized structures from inert matter, cease to be performed; and it is given up to the influence of chemical forces only, which speedily occasion a separation of its elements, and cause them to return to their original forms, namely, water, carbonic acid, and ammonia. It is not, however, in the dead organism alone, that this decomposition occurs; for it is certain that *interstitial* death and decay are incessantly taking-place during the whole life of the being; and that the maintenance of its healthy or normal condition depends upon the constant removal of the products of that decay, and upon their continual replacement. If, on the one hand, those products be retained, they act in the manner of poisons; being quite as injurious to the welfare of the body as the most deleterious substances introduced from without. On the other hand, if they be duly carried-off, but be not replaced, the conditions essential to vital action are not fulfilled, and the death of the organism must be the result.

35. Now it is to be observed that, as Plants obtain the chief materials of their *growth* from water and carbonic acid, taking the carbon from the latter and setting-free the oxygen, so do they require, as the condition for their *decay*, the presence of oxygen, which may reunite with the carbon that is to be given back to the atmosphere. If secluded from this, the vegetable tissues may be preserved for a long time without decomposition. Generally speaking, indeed, they are not prone to rapid decay, except at a high temperature; and hence it is that we have so little evidence, in Plants, of that constant interstitial change of which mention has just been made. Its existence, however (at least in all the softer portions of the structure), is made evident by the fact, that

a continual extrication of carbonic acid takes-place, to an amount which sometimes nearly equals that of the carbonic acid decomposed, and of the oxygen set-free, in the act of Nutrition (§ 23). The latter operation is only effected under the stimulus of sun-light; the former is constantly going-on, by day and by night, in sunshine and in shade; and if it be impeded or prevented by want of a due supply of oxygen, the plant speedily becomes unhealthy.—Now this extrication of the products of interstitial decay is termed *Excretion*. It is usually confined in Plants to the formation of carbonic acid and water, by the union of the particles of their tissues with the oxygen of the air; a process identical with that which occurs after the death of the entire structure. But in Animals it is much more complicated, owing to the larger number of constituents in their fabric, and to the much greater variety in the proportions in which these are combined; hence the products of interstitial decomposition are much more numerous and varied, and several distinct modes are devised for getting-rid of them. Moreover, as the Animal tissues are much further removed than the Vegetable from the composition of Inorganic bodies, they are subject to much more rapid and constant decay; and we shall find that this decay is so considerable in amount, as to require on the one hand a very complex excretory apparatus to carry-off the disintegrated matter, and on the other a large supply of nutrient material to replace it.

36. The preceding history may be thus summed up.—I. The presence of the active Vegetable cell-germ or reproductive molecule, under conditions hereafter to be specified (Sect. 3), occasions the combination of certain inorganic elements into new and peculiar compounds. These compounds, however, exhibit no properties that distinguish them from others in which ordinary *Chemical* agencies have been concerned; and we may, therefore, regard the first act of the Vegetable cell-germ as essentially chemical in its nature. The Animal cell-germ does not possess the same Chemical power; it is not capable of decomposing the water, carbonic acid, and ammonia, which include the elements of its tissues; and it is entirely dependent for its growth, upon the supply of nutriment previously prepared for it by the agency of the vegetable kingdom.—II. The cell-germ then exerts an *Assimilating* agency upon the *pabulum* thus prepared; by which a new arrangement of its particles is produced. This new arrangement gives new and peculiar qualities to the fluid, which show that it is something more than a mere chemical compound, and that it is in the act of undergoing the process of organization.—III. The *Formation* of this elaborated pabulum into tissue then takes-place; its materials are withdrawn from the fluid, and incorporated with the solid texture; and in thus becoming part of the organized fabric, they are caused to exhibit its own peculiar properties.—IV. At the same time, another portion of this pabulum may be gradually prepared to serve as the germ of a

new cell, or set of cells, by which the same properties are to be exhibited in another generation.—v. By an operation resembling that concerned in the first preparation of the pabulum, certain products, more or less differing from it in character, but not destined to undergo organization, are formed in the cavity of the cell.—vi. A decomposition or disintegration of the organized structure is continually going-on, by the separation of its elements into simpler forms, under the influence of purely Chemical attractions; and the setting-free of these products by an act of excretion, is thus incessantly restoring to the Inorganic world a portion of the elements that have been withdrawn from it.—vii. When the term of life of the parent-cell has expired, and its reproductive molecules are prepared to continue the race, the actions of nutrition cease; those of decomposition go-on unchecked; and the death of the structure, or the loss of its distinguishing vital properties, is the result. By the decomposition which then takes place with increased rapidity, its elements are restored to the Inorganic world; presenting the very same properties as they did when first withdrawn from it; and becoming capable of being again employed, by any successive numbers of living beings, to go through the same series of operations.

37. Thus, then, we see that our fundamental idea of the properties of the simplest Living being consists in this;—that it has the capability of drawing into its own substance certain of the elements furnished by the inorganic world;—that it forms these into new combinations (which the chemist *may* find out methods of imitating);—that it re-arranges the particles of these combinations, in that peculiar mode which we call 'organization;'—that in producing this new arrangement, it renders them capable of exhibiting a new set of properties, which we call 'vital,' and which are manifested by them, either as connected with the parent organism, or as appertaining to the germs of new structures, according to the mode in which the materials are applied;—that notwithstanding its peculiar condition, it remains subject to the ordinary laws of Chemistry, and that decomposition of its structure is continually taking-place; and finally, that the duration of its vital activity is limited; the changes which the organic structure undergoes, in exhibiting its peculiar actions, being such as to render it (after a longer or shorter continuance of them) incapable of any longer performing them.

38. There is abundant evidence, that the duration of the *Life*, or state of *Vital Activity*, of an organized structure, is inversely proportioned to the degree of that activity; and consequently, that Life is shortened by an increased or abnormal activity, whilst it may often be prolonged by influences which diminish that activity. Thus, we shall hereafter find reason to believe, that the duration of life in the Muscular and Nervous tissues of Animals, is entirely

dependent upon the degree in which they are exercised; every call upon their activity causing the death and disintegration of a certain part; whilst if they be allowed to remain in repose for a time, only that amount of decomposition will take-place, to which their chemical character renders them liable. Again, we may trace the connection between the vital activity of a part and the duration of its life, by comparing the transitory existence of the *leaves* of a Plant, which are its active organs of nutrition, with the comparative permanence of its woody *stem*, the parts of which, when once completely formed, undergo very little subsequent change. The most striking manifestation of this connection, however, is afforded by that condition, in which, without any appreciable amount of vital activity or change, an organized structure may remain unaltered for centuries; not only presenting at the end of that time its original structure, but being prepared to go through its regular series of vital operations, as if these had never been interrupted. This state may be designated as *Dormant Vitality*. It differs, on the one hand, from *Life;* because Life is a state of *activity*. On the other hand, it differs from *Death;* because death implies not merely a suspension of activity, but a total *loss of vital properties*. Now in the state of Dormant vitality, the vital properties are retained; but they are prevented from manifesting themselves, by the want of the necessary conditions. When these conditions are supplied, the state of vital activity is resumed, and all the functions of life go on with energy.

39. Of this Dormant Vitality it may be well to adduce some examples which may assist in impressing on the mind of the student the general views here put-forth. This condition is manifested in the most remarkable manner by the seeds and germs of plants; many of which are adapted to remain, for an unlimited period, in a state of perfect repose, and yet to vegetate with the greatest activity, so soon as they meet with the necessary conditions. Thus the sporules of the Fungi, which can only develope themselves in decaying organized matter, seem universally diffused through the atmosphere, and ready to vegetate with the most extraordinary rapidity, whenever a fitting opportunity presents itself. This at least appears to be the only feasible mode of explaining their appearance, in the forms of Mould, Mildew, &c., on all moist decaying substances; and that there is no improbability in the supposition itself, is shown by the excessive multiplication of these germs, a *single individual* producing not less than *ten millions* of them, so minute as when collected to be scarcely visible to the naked eye, rather resembling thin smoke, and so light as to be wafted by every movement of the atmosphere; so that, in fact, it is difficult to imagine any place from which they can be excluded.—Moreover, it is certain that an equally tenacious vitality exists in the seeds of higher plants. Those of most species inhabiting temperate climates are adapted to

remain dormant during the winter; and may be easily preserved, in dry air, and at a moderate temperature, for many years. Some of those which had been kept in the Herbarium of Tournefort during upwards of a century, were found to have preserved their fertility. Cases are of no unfrequent occurrence, in which ground that has been turned-up, spontaneously produces plants dissimilar to any in their neighbourhood. There is no doubt that in some of these cases, the seed is conveyed by the wind, and becomes developed in spots which afford congenial soil, as already remarked in the case of the Fungi. Thus it is commonly observed that clover makes its appearance on soils which have been rendered alkaline by lime, by strewed wood-ashes, or by the burning of weeds. But there are many authentic facts, which can only be explained upon the supposition that the seeds of the newly-appearing plants have lain for a long period imbedded in the soil, at such a distance from the surface as to prevent the access of air and moisture; and that, retaining their vitality under these circumstances, they have been excited to germination when at last exposed to the requisite conditions. Thus Professor Lindley states as a fact, that he has raised three raspberry-plants from seeds taken from the stomach of a man, whose skeleton was found thirty feet below the surface of the earth, at the bottom of a barrow which was opened near Dorchester; as his body had been buried with some coins of the Emperor Hadrian, there could be no doubt that the seeds were 1600 or 1700 years old. Again, there are undoubted instances of the germination of grains of wheat, which were enclosed in the wrappers of Egyptian mummies, perhaps twice that number of years ago; the wheat being different in some of its characters from that now growing in the country.

40. These facts make it evident, that there is really no limit to the duration of this condition; and that when a seed has been thus preserved for ten years, it may be for a hundred, a thousand, or ten thousand, provided that no change of circumstances either exposes it to decay, or calls its vital properties into activity. Hence in cases where seeds have been imbedded deep in the earth, not by human agency, but by some geological change, it is impossible to say how long anteriorly to the creation of man they may have been produced and buried; as in the following very curious instance:—Some well-diggers in a town on the Penobscot river, in the State of Maine (New England), about forty miles from the sea, came at the depth of about twenty feet upon a stratum of sand; this strongly excited curiosity and interest, from the circumstance that no similar sand was to be found anywhere in the neighbourhood, and that none like it was nearer than the sea-beach. As it was drawn up from the well, it was placed in a pile by itself; an unwillingness having been felt to mix it with the stones and gravel which were also drawn up. But, when the work was about to be finished, and the pile of stones and

gravel to be removed, it was necessary also to remove the sand-heap. This, therefore, was scattered about the spot on which it had been formed, and was for some time scarcely remembered. In a year or two, however, it was perceived that a number of small trees had sprung from the ground over which the heap of sand had been strewn. These trees became in their turn objects of strong interest, and care was taken that no injury should come to them. At length it was ascertained that they were Beach-Plum trees; and they actually bore the Beach-Plum, which had never before been seen, except immediately upon the sea-shore. The trees had therefore sprung from seeds, which were in the stratum of sea-sand that had been pierced by the well-diggers. By what convulsion they had been thrown there, or how long they had quietly slept beneath the surface, cannot possibly be determined with exactness; but the enormous length of time that must have elapsed, since the stratum in which the seeds were buried formed part of the sea-shore, is evident from the accumulation of no less than twenty feet of vegetable mould upon it.

41. Numerous instances will be related in the succeeding Chapter, of the occurrence of a similar condition in fully-developed Plants, and even in Animals of high organization. In some of these it is a regular part of the history of their lives, coming-on periodically like sleep; whilst in others it is capable of being induced at any time, by a withdrawal of some of the conditions essential to vital activity. In regard to all of them, however, it may be observed that the vitality can only be retained, when the organized structure itself is secluded from such influences as would produce its decay. Thus, the hard dry tissue of the seed is but little liable to decomposition; and all that is usually required for the prevention of change in its structure, is seclusion from the free access of air and from moisture, and a steady low or moderate temperature. If a seed be exposed to air and moisture, but the temperature be not high enough to occasion its germination, it will gradually undergo decay, and will consequently lose its vitality. The animal tissues are more liable, as already mentioned, to spontaneous decomposition; and the only instances in which they can retain their vitality for a lengthened period, without any nutritive actions, are those in which all decomposition is prevented, either by the action of cold, or by the complete deprivation of air or of moisture,—as when Frogs, Snakes, &c., have been preserved for years in an ice-house, or Wheel-Animalcules have been dried upon a slip of glass.

42. The class of phenomena last brought under notice, serves to exhibit in a very remarkable manner the dependence of all Vital Action upon certain *other* conditions than those furnished by the organized structure alone. Thus a seed does not germinate *of itself;* it requires the influence of certain external agencies, namely, warmth, air, and moisture; and it can no more produce a plant without the

operation of these, than warmth, air, and moisture could produce it without a germ prepared by a pre-existing organism. Now when we come to study these conditions, we find that they may be arranged under two categories, the *material* and the *dynamical*. Thus, a seed cannot germinate without sufficient water to bring the contents of its cells into a state in which their chemico-vital reactions can take place; and it must be surrounded with an atmosphere containing oxygen, since without the presence of this element the necessary chemical transformations cannot go on. Thus oxygen and water are the *material* conditions required by the germinating seed; in almost every other case, alimentary matters are required in addition; but these the seed possesses within itself. Even if supplied, however, with an unlimited amount of water and oxygen, the seed cannot germinate, unless it be acted-on by Heat; and this, in fact, may be considered with great probability, as supplying the *force*, of which not merely the chemical transformations, but the growth and development of the tissues of the Plant, are the manifestation. This view will be more fully developed hereafter (Sect. 3).

43. This dependence of *Vital* actions upon certain external Agencies, as well as upon the properties of the Organism which manifest them, is no greater than the dependence of any of the phenomena exhibited by an Inorganic substance, upon some other agency external to itself. In fact, *no change whatever can be said to be truly spontaneous;* that is, no property can manifest itself, unless it be called into action by some stimulus fitted to excite it. Thus, when spontaneous decomposition (as it is commonly termed) occurs in an organized or an inorganic substance, it is due to the forces generated by the mutual attraction between certain elements of the substance and the oxygen of the atmosphere, this attraction being sufficient to overcome that which tends to hold together the particles in their original state. If the air be totally excluded, decay will not take place;* because no new force comes into operation, to cause a separation of the components from their original modes of union. The influence of the Dynamical conditions which are essential to Vital activity, will be fully explained in the next Chapter; and at present it will be sufficient to remark, that the degree in which they are supplied possesses a well-marked influence upon the amount of activity and energy manifested in the actions of the organized structure; that there is a limitation in the case of each of them, as to the degree in which it can operate beneficially, the limitation being usually narrower and more precise, according to the elevation of the being in the scale; that an excessive supply may be destructive to the vital properties of the organism, by over-

* On this principle, meats, vegetables, and even liquid soups, are now largely preserved, for the use of persons undertaking long voyages, by enclosing them in tin cases, carefully soldered-up. There is no limit to the time during which decomposition may thus be prevented.

stimulating it and thus causing it to live too fast, or by more directly producing some physical or chemical change in its condition; and that a deficiency will keep-down or suspend all vital activity, leaving the structure to the unrestrained operation of those agencies which are always tending to its disintegration, and consequently occasioning a speedy loss of the vital properties,—save in those cases in which they may be preserved in a dormant condition, and which are exceptions to the general rule, that the death or departure of the vital properties follows closely upon the cessation of vital actions.

44. Our fundamental idea of *Life*, then, is that of a state of constant change or action; this change being manifested in at least two sets of operations;—the continual withdrawal of certain elements from the inorganic world;—and the incorporation of these with the peculiar structures termed organized, or the production from them of the germs that are hereafter to accomplish this. As the *conditions* of this continual change, we recognize the necessity of an *organized structure* on the one hand, or of a germ which is capable of becoming so; whilst we also perceive the necessity of a supply of certain kinds of matter from the inorganic world, capable of being combined into the materials of that structure, which may be designated as the *alimentary substances;* and, further, we see that the organism can exert no influence upon these, except with the assistance of certain dynamical agencies, such as light, heat, &c., that supply the *forces* or *powers* without which no change can occur. And to these forces, acting under the conditions which the Organized body alone can supply, may be attributed (as will hereafter appear) the phenomena which we distinguish as Vital.

45. But just as we find among Inorganic bodies, that various kinds are to be distinguished by their different properties, whilst all agree in the general or essential properties of matter, so do we find that living organized substances are distinguished by a variety of properties inherent in themselves, whilst they all agree in the foregoing general or essential characters. In many instances, the difference of their properties is as *obviously* coincident with differences in their structure and composition, as it usually is among the bodies of the Mineral world: thus we find the property of Contractility on the application of a stimulus, to be for the most part restricted to a certain form of organized tissue, the Muscular; and we find that the property whereby such a stimulus is capable of being received and conveyed to a distance, seems to be restricted to another kind of tissue, the Nervous. In a great number of cases, however, very obvious differences in properties manifest themselves, when no perceptible variations exist, either in structure or composition; thus it would be impossible to distinguish the germ-cell of a Zoophyte from that of Man, by any difference in its aspect or composition; yet neither can be developed into any other form than

that of its parent species, and they must be regarded, therefore, as essentially different in properties. In the same manner we shall find that, in the same organized fabric, there are very great varieties in the actions of its component cells, which indicate a similar variety in their properties; and yet they are to all appearance identical. But there can be no reasonable doubt that differences really exist in such cases, though our means of observation are not such as to enable us to take cognizance of them, by the direct impressions they make upon our senses. Analogous instances are not wanting in the Mineral world; for the Chemist is familiar with a class of compounds designated *isomorphous*, in which, with perfect similarity in external form and physical properties, there is a difference, more or less complete, in chemical composition, and consequently in the effects of re-agents.

46. Whatever may be the *peculiar* vital properties possessed by an organized tissue, we find that they are always dependent upon the maintenance of its characteristic structure and composition, by the nutritive operations of which we have spoken; and that their existence forms a part, as it were, of the more general phenomena of its Life. They manifest themselves with the first complete development of the tissue; they are retained and exhibited so long as active nutritive changes are taking place in it; their manifestation is weakened or suspended if the nutritive operations be feebly exerted; and they depart altogether, whenever, by the cessation of those actions, and the uncompensated influence of ordinary Chemical forces, the structure begins to lose that normal composition and arrangement of parts, which constitutes its state of *organization*. Hence we may regard these peculiar properties as conformable, in all the essential conditions of their existence, with those more general properties which have been previously dwelt-upon as characterizing a living organized structure.

3. *Of the Forces concerned in the Production of Vital Phenomena.*

47. In prosecuting his inquiry into the *causes* of those phenomena of Living organisms, which, being of a totally different order from those of Inorganic matter, are distinguished as Vital, the Physiologist must take as his guide those methods of investigation which have proved successful in other departments of scientific research. If he turn, then, to the sciences of Mechanics, Optics, Thermotics, Electricity, Magnetism, or Chemistry, he finds that the phenomena which they respectively comprise are referable to the operation of certain *forces*, and that what are termed the *laws* of those sciences are nothing else than expressions of the *conditions of action* of those forces. Thus in Mechanics we have principally to do with the *motion* of masses of matter, and our idea of *force* is chiefly derived from our own experience of the exertion of a *power* in pro-

ducing or resisting motion; whilst the '*laws*' of Mechanics are nothing else than expressions of the conditions, under which the forces or powers that produce motion operate upon matter. So in Optics, we have to do with the force which we term *light;* and the laws of Optics are expressions of the conditions under which that force is propagated, and of its action on material substances. In Thermotics, again, we have to do with the force of *Heat;* and its laws are expressions of the circumstances under which heat is propagated, and of the changes which it occasions in the substances it affects. So in the sciences of *Electricity* and *Magnetism*, we have to do with the forces known under those names; and with the laws expressive of their action upon matter. And the scientific Chemist refers all the phenomena with which he is concerned to the operations of *Chemical Affinity*, and endeavours to deduce from observation of the phenomena the laws of the operation of this force.—So the Physiologist will be justified in assuming a *Vital Force* (or *Forces*) as the power which operates in producing Vital phenomena; and will most legitimately pursue his science, in inquiring into the conditions under which that force operates.

48. The analogy of the Physical Sciences may be advantageously pursued further.—Although we are accustomed to speak of the Mechanical power that produces Motion, of Light, of Heat, of Electricity, of Magnetism, and of Chemical Affinity, as *distinct forces*, yet it has gradually become apparent that very intimate relations subsist between them, and that they are, in fact, mutually convertible; so that one force (A) operating upon a certain form of matter, ceases to manifest itself, but developes another force (B), in its stead; whilst, in its turn, the second force (B) may be reconverted into the first (A), or into some other (C), which, again, may reproduce either the first (A) or second (B), or some other (D or E). —It was in the case of Electricity and Magnetism, that this reciprocal relation, which is designated as 'correlation,' was first clearly apprehended. If an electric current be passed round a piece of soft iron, that iron becomes magnetic, and remains so as long as the current is circulating: on the other hand, from a magnet put in motion, an electric current may be obtained. Hence,we are accustomed to connect these two forces under the term Electro-Magnetism; but they can be easily shown to be quite distinct in their modes of operation on matter; and their relation is not really more intimate than that of other forces. For Heat may be developed by Electricity; as when a galvanic current, sent through a thin platinum wire, heats it to ignition, or even fuses it. Conversely, Electricity may be developed by Heat; as when heat is applied to bars composed of dissimilar metals in contact with each other. Again, if Mechanical Motion be retarded, as in *friction*, we immediately have a development either of Heat or of Electricity; heat alone being developed, when the two rubbing surfaces are com-

posed of precisely the same substance; and electricity being produced, when these substances are different. And it is for the most part through the medium of Heat or Electricity, that the force of Mechanical Motion is 'correlated' to Light, Magnetism, and Chemical Affinity.

49. The idea of correlation also involves that of *a certain definite ratio*, or *relation of equivalence*, between the two forces thus mutually interchangeable; so that the measure of force B, which is excited by a certain exertion of force A, shall in its turn, give rise to the same measure of force A, as that originally in operation. Thus, when an electric current is set in motion by galvanic action, we have a conversion of chemical force (which has manifested itself in the decomposition of the water and the oxidation of the zinc) into electrical; but the electric current may, in its turn, be made to produce chemical decomposition; and the amount of this kind of change which it will effect, bears a precise correspondence (*cæteris paribus*) with the amount of zinc which has undergone oxidation in the galvanic cell. In like manner, when water at 212° is converted into steam, the heat which it receives is no longer manifested *as* heat, but mechanical force is developed in its stead, and this in a certain definite ratio, so that the 'mechanical equivalent' of heat is capable of being exactly determined: so soon, however, as the steam, losing its elasticity by condensation, returns to the condition of water, the original equivalent of heat is again developed, its mechanical force being no longer manifested.*

50. Now in every case in which one force is thus converted into another, the change is effected through the medium of a certain form of matter, or *material substratum*. This may be, in some cases, of almost any description whatever; as when Heat is produced by the friction or retarded motion of solids, liquids, or even gases; or when Motion (as shown in expansion) is produced by the application of heat to any kind of material substance. But in other cases, the change can only be effected through some *special* form of matter; or, if several substances may serve as its medium, there is some one which is greatly superior to all the rest, in the readiness with which a certain force manifests itself through

* The above statement is an expression of the simple facts of the case, which, when thus understood, render the hypothesis of 'latent heat' altogether unnecessary. This hypothesis, however ingenious, will doubtless share the fate of many other such attempts to substitute a form of words for realities. It supposed the 966 degrees of heat expended in converting a certain amount of water at 212° into steam at 212°, to become altogether *inactive* or *latent*; and gave no account whatever of the mechanical force which is produced in that act of conversion. The idea of an *inactive force*, in fact, is one that cannot be entertained; for if a force ceases to be active, it is no longer 'force.' And it cannot be imagined that force, any more than matter, should cease to exist; it *must* manifest itself under some other aspect.—For a complete exposition of the mutual relations existing among the above-named agents, see Prof. Grove's treatise "On the Correlation of the Physical Forces."

it. Thus *iron* is the substance through which Electricity can best be converted into Magnetism; and the development of magnetic force, therefore, is most readily effected through this medium. So, Heat is more readily converted into Electricity through a combination of bismuth and antimony, than through any other metals; and the affection of Light by magnetic force (discovered a few years since by Prof. Faraday), though producible through any transparent substance, can be made much more obvious when the magnetism is made to act upon a peculiar glass composed of vitrified borate of lead, than through the medium of any other substance yet known.—This *speciality* in the action of different substances, when subjected to the same forces, is a fact of fundamental importance; and it is on it, indeed, that our notion of their several *properties* depends.

51. Now as the properties of every kind of matter require certain conditions for their manifestation, our acquaintance with them entirely depends upon whether the conditions of their action have been afforded. Thus, to go back to a former illustration, supposing a new chemical element to be discovered, we could not know its properties in regard to heat, electricity, or magnetism, the mode of its combination with other elements, the nature and properties of the compounds produced, their reactions with other compounds, &c., until we have tried a complete series of experiments upon it,—that is, until we have placed it in all the circumstances or conditions requisite to manifest the properties with which we seek to become acquainted, or whose absence we seek to determine if they do not exist. Now we might have made all the experiments we could devise upon such a body; and yet we might have failed in detecting some remarkable and distinguishing property inherent in it, simply because we had not placed it in the requisite circumstances for the manifestation of this peculiarity. Further, even in the elements or compounds with which we are best acquainted, it is very possible that properties exist, of which we as yet know nothing, simply because they have not yet been called into action by the requisite combination of conditions. For example, no one would have thought it possible, a few years since, that water could be *frozen* in a *red-hot* metallic vessel; and yet this is now known to be effected with ease and certainty, by a proper arrangement of the circumstances.

52. Again, the properties of a compound substance are, in general at least, altogether different from those which present themselves in either of its components; so that we could not in the least degree judge of the former from the latter, or of the latter from the former. What more different, for example, than the physical and chemical properties of Water, from those of either the Oxygen or the Hydrogen that enter into its composition? Or what more different than the properties of a neutral salt, from those of the acid and alkali from whose union it is produced?

53. Further, the physical properties of a substance may be completely changed, by an alteration in its condition as regards Heat or any other of the forces already mentioned. For example, the particles of water have so strong an attraction for each other, at a low temperature, as to become aggregated in a crystalline form, and to produce a dense solid mass; at somewhat a higher temperature, their mutual attraction is so slight that a very small amount of mechanical force is sufficient to separate them, and they move upon each other with the utmost freedom; whilst at a still higher temperature, they manifest a power of mutual repulsion, which increases very rapidly with every augmentation of heat. Yet when the temperature of the substance is lowered to its former standards, we observe that it first returns to the liquid, and then to the solid form; and that, in those states, it manifests all the properties which before characterized it.

54. Not merely the physical, but the chemical properties of bodies may be affected by a change in their mechanical condition. Thus, it is well known that oxygen and iron, at ordinary temperatures, have a mutual affinity, which is only sufficient to produce a slow combination between them; whilst at high temperatures, that affinity is such as to cause their rapid and energetic union. Now if iron, in a state of very minute division, such as it possesses when set-free from the state of oxide by means of hydrogen, at the lowest possible temperature, be brought into contact with oxygen or even with atmospheric air, at ordinary temperatures, it immediately becomes red-hot, and is converted into an oxide. The minuteness of the division, predisposing to chemical union, appears to be the occasion of our power of causing many substances to combine, when one or both are in the *nascent* state (that is, when just set-free from some other combination), which could not be made to unite in any more direct manner; thus, when a quantity, however minute, of any preparation of arsenic, is dissolved in fluid in which hydrogen is being generated, the hydrogen will detach the metal from its previous combination, and will pass-forth in union with it, as arseniuretted hydrogen, a compound which cannot be formed by the direct union of the elements. In like manner, in that mechanical mixture of three finely-divided substances, which we call gunpowder, the rapidity with which combustion is propagated through the largest collection of it, is entirely dependent upon the minute subdivision of its components, and the very close approximation of their particles. Hence it may be very correctly said, that the true chemical properties of the substances are not manifested, except when these are in a state of very minute division; and that they are in fact obscured by the aggregation of the particles into masses.—Thus, then, we are at no loss to discover examples, in the inorganic world, of an alteration in the sensible properties, both Chemical and Physical, of the bodies composing it, by a change in

the conditions in which they are placed. And it may be stated as a general fact, that we never witness the manifestation of new properties in a substance, unless it has undergone some change in its own condition, of which altered state these properties are the necessary attendants.

55. Now if we apply the same methods to the phenomena of Life, we shall see that they will lead to a mode of viewing them, which will considerably tend to the simplification of Physiological science. —In the first place, we have to look at these phenomena as the results of certain *forces*, acting through those forms of matter which we term Organized; and these forces we shall provisionally designate as Vital. Thus in the growth of the simple Vegetable cell, as already described (§§ 21—36), we trace the operation of a force closely allied to ordinary *chemical affinity*, but so far different that it can only be exerted through a living organism; of a force of *assimilation* or vital transformation; and of a force of *organization* and complete vitalization. Now although we may provisionally designate these as distinct forces, on account of the diversity of their manifestations, it is impossible not to see that they are mutually dependent, and that they form the successive elements of a continuous series of phenomena belonging to the same category, that of *cell-life;* and further, we observe that they operate under the same conditions, namely, the presence of a cell-germ and of the materials of its growth, and the action of light and heat. Again, in the *multiplication* of the original cell, by whatever method performed, we cannot but trace the continued action of forces of the same character; since this operation takes-place as a continuation of the process of growth, and under precisely the same influences. Further, we occasionally meet with examples, even among the simplest forms of Vegetation, of very active *movement;* thus the filaments or elongated cells of the *Oscillatoriæ* are continually bending themselves backwards and forwards, with a regular rhythmical undulation; and the 'zoospores' of the *Confervæ* are propelled through the water by the rapid vibration of the cilia with which they are furnished (§ 234). Now that such a production of a purely physical change is a manifestation of vital force, is obvious from this, —that it takes place only while the vitality of the organism endures, and that it is dependent upon the very same conditions as the other vital operations require; and it is further interesting to remark in the case of the 'zoospores,' that it seems to take the place of the operations of growth, for these do not commence until the movement of the spore has ceased. The spiral filaments, again, which have been discovered in most of the higher Cryptogamia, and which seem to perform the same function with the spermatozoa of Animals (§ 243), have a like spontaneous movement, which must be looked-upon as an expression of *their* vital force. Many cases of motion produced by a change of form of certain contractile

cells, might be cited from among the higher tribes of the Vegetable kingdom; these movements being sometimes rhythmical and spontaneous, as in the *Hedysarum gyrans*,—sometimes taking-place only in respondence to stimulation, as in the *Dionæa muscipula* (Venus's fly-trap),—and sometimes occurring as part of the series of ordinary vital phenomena, although producible also by stimulation, as in the *Mimosa pudica* (sensitive-plant), which regularly closes its leaves at night, but will do so at any time when they are touched or otherwise irritated.* These movements only take-place during the life of the Plant; and it is particularly observable in the last-named species, that the facility with which they may be excited in any individual, is closely related to the activity of its vegetating processes.—Thus even in the Plant, we see that the Vital forces manifest themselves, not merely in *growth*, but in *movement*.

56. When we examine the structure of one of the higher Plants, we find that although the principal part of its fabric is still made-up of unmetamorphosed cells, yet certain portions of it have undergone *histological transformation;* that is, its primordial cells have lost their original character, having been changed into other kinds of tissue. This transformation takes-place to a much greater extent in the Animal body; in which the variety of actions to be performed is much larger, and in which we accordingly find a much greater variety of tissues developed as their instruments. But however widely these tissues may depart from their original character, we find that the process of transformation takes-place under the same conditions as that of growth, and must be regarded as continuation of it; being, in fact, the special manifestation of vital force in one set of cells, as multiplication is in another, or as motion in another. And we shall find, that, in proportion as this transformation takes place, do the tissues lose their proper vital endowments; for it may be stated as a general fact, that even in the most complicated and elaborate Animal organism, *the most active vital operations are usually performed by tissues which retain their original cellular constitution with little or no change.*

57. Further it is to be observed, that as it is the peculiar character of such organisms that each of their parts should be appropriated to some distinct office which it is specially adapted to perform, so do we find that the cells which become the instruments of some one particular kind of operation seem to lose their other endowments; as if the expenditure of the vital force of each cell upon any one purpose, unfitted it for any other agency. Of this we shall meet with numerous examples hereafter; it will be sufficient here to refer to two of the most characteristic. It is necessary for every act of Secretion, that a set of cells should be formed within the

* For a fuller analysis of these phenomena, see the Author's "Principles of Comparative Physiology," CHAP. XII.

ultimate follicles of the Gland which is the instrument of the function (§ 241); and these ultimate follicles may really be regarded as parent-cells, which produce the true secreting cells in proportion as the materials of their growth are supplied by the blood. Now these parent-cells themselves possess no secreting power, their vital force being entirely expended in the production of the true secreting cells. On the other hand, the true secreting cells possess no reproductive power, but die and are cast-off when they have reached their maturity; as if their whole vital force were expended in the secreting process, which is nothing else on their parts than an act of growth. So, again, the cells which constitute the fibrillæ of Muscular fibre, and of whose change of form the contraction of the muscle is the result (§ 336), exercise no power of chemical transformation, undergo no histological change, and appear to be entirely destitute of the power of self-multiplication; the expenditure of their vital force in the act of muscular contraction involves their death and disintegration; and their renewal appears to be accomplished by a production of new cells from the nucleus of the Myolemma (§ 338), which, itself possessing no contractile power, retains its reproductive capacity.

58. Hence, then, we have reason to believe that all the truly *Vital* phenomena, however diversified, are but results of the operation of one and the same Force, whose particular manifestations are determined by the nature of the material substratum through which it acts; the same fundamental agency producing simple *growth* in one case, *transformation* in another, *multiplication* in a third, *mechanical movement* in a fourth, whilst in a fifth it developes *nervous power*, which may itself operate in a variety of different modes. Such a view seems fully justified by the consideration, (1) that all these forces are exerted, even in the most highly-organized living being, through a common instrumentality, the simple cell; (2) that the entire assemblage of cells making-up the totality of any organism, have all a common parentage, being lineally descended from the single primordial cell in which it originated; and (3) that they are manifested in connection with each other, as parts of the life of each individual cell, in those simple organisms which are the lowest members of the two kingdoms respectively, and in which there is no separation or specialization of function.

59. The question next arises,—what is the source of the Vital Force, of which the phenomena of Life are the manifestations; and under the guidance of the ideas derived from Physical Science, we shall have no difficulty in referring it to the operation of those external agencies, the influence of which has long been known to be essential to Vital action, and which have been usually designated by the term *Vital Stimuli*. Thus, the growing Vegetable cell cannot decompose carbonic acid, except when acted-upon by Light; and the amount of this change which it effects, is in strict ratio (*cæteris*

paribus) with the illuminating power of the rays which it receives (§ 86). So, again, neither Plants nor Animals can maintain their activity, except under the continual influence of a certain measure of Heat; and the amount of that activity will be shown to bear a constant ratio, in all those tribes which have no independent power of sustaining it, to the quantity which they receive from external sources (CHAP. II. Sect. 2); this being true, not merely of the general rate of the Vegetative actions of growth and development, but also of those manifestations of vital power which are peculiar to Animals. Thus we may say that Light and Heat acting upon the Organic germ, become transformed into Vital force, in the same manner as Heat acting upon a certain combination of metals becomes Electricity, or as Electricity acting upon iron developes itself as Magnetism; and we shall find that this view is in complete harmony with all the phenomena of Vital action. Moreover, the Vital force thus engendered frequently manifests itself in producing Physical or Chemical phenomena; thus completing that *mutual* relationship, or correlation, which has been shown to exist among the Physical and Chemical forces themselves (§§ 48, 49). Of this we have already seen an instance, in the *movements* produced by muscular contraction and by ciliary vibration. The production of *heat* by certain Plants and by warm-blooded Animals, is another apposite exemplification of the same principle. But the most remarkable illustration is undoubtedly derived from the Nerve-force; which, whilst itself a peculiar form of the general Vital force, and capable of affecting all the other manifestations of the same force (as in the modifications which it produces in the processes of Nutrition and Secretion, as well as in exciting Muscular Contraction), is capable of developing Electricity as well as Light and Heat, and is also capable of being called-forth by the action of Light, Heat, Electricity, Chemical Affinity, or even Mechanical Motion, on the Nervous tissue. It is a most remarkable confirmation of the views here advanced, that the Nerve-force, which must be accounted, in its relations to Mind, as the highest of all the forms of Vital force, should yet be the one which is most directly and intimately related to the Physical forces,—the 'correlation' even of Electricity and Magnetism not being more complete, than the 'correlation' of Electricity and Nerve-force may be shown to be (§ 396).

60. Thus, then, not only are the *materials* drawn from the Inorganic world by vital agencies, given-back to it again by the disintegration of the living structures of which they form a part; but all the *forces* which are operative in producing the phenomena of Life, being first derived from the Inorganic universe, are returned to it again under some form or other. The Plant forms those organic compounds, at the expense of which Animal life (as well as its own) is sustained, by the decomposition of carbonic acid, water, and ammonia; and the *light*, by whose agency alone this process can be

effected, may be considered as metamorphosed into the peculiar *affinity*, by which the elements of these compounds are held together. The *heat* which Plants receive, acting through their organized structures as Vital force, serves to augment these structures to an almost unlimited extent, and thus to supply new instruments for the agency of light and for the production of organic compounds. The whole *nisus* of Vegetable life may be considered as manifested in this production; and, in effecting it, each organism is not only drawing *material*, but *force*, from the universe around it. Supposing that no Animals existed to consume these organic compounds, they would be all at last restored to the inorganic condition by spontaneous decay, which would reproduce the carbonic acid, water, and ammonia, from which they were generated. In this decay, however slow, heat and light are given out, in the same amount as when more evidently produced in the ordinary combustive process; and this sometimes occurs even during the life of the plant, whose vital movements, also, may be considered as restoring to the Inorganic universe a certain measure of the force they have derived from it under other forms. So, in making use of the stores of Coal which have been prepared for his wants by the luxuriant Flora of past ages, Man is not only restoring to the atmosphere the carbonic acid, the water, and the ammonia, of the Carboniferous period; but is actually reproducing, and applying to his own purposes, the Light and Heat which were operating to produce the growth of vegetation at that remote period in the Earth's history.

61. But the organic compounds which the agency of Light and Heat upon the Vegetable structures has produced, are designed for a much higher purpose than that of being merely given back to the Inorganic universe by decay or combustion; and the forces which hold together their elements have a much more exalted destiny. In serving as the food of Animals, a part of them become the materials of their organized tissues, and the instruments through which the nervous and muscular forces are developed; whilst another part are applied to sustain the combustive process, by which the heat of the higher classes is maintained quite independently of the external supply of that force. The greater part of the Animal kingdom, however, is dependent, like the Vegetable, upon the Inorganic Universe, for the Heat which serves as its organizing force; and it is only under the constant influence of this agent, that the operations of growth, development, and maintenance can take place. The Animal is not dependent like the Plant upon Light; and this is obviously because this agent is chiefly concerned in that preliminary operation, by which the organic compounds are generated as the pabulum of the growing tissues; in fact, the embryo within the germinating seed, which, like the animal, is nourished upon matter previously prepared for it, is most rapidly developed in the absence of light, up to the time when, its store being ex-

hausted, its further supplies must be obtained by its own instrumentality.

62. The Vital activity of Animals, then, may be considered as chiefly sustained by the Chemical forces subsisting in their food, which are set-free when the elements are reconverted to their original state; and by the Heat which they derive from external sources, or from the combustion of a part of their food. These forces may be considered as in a state of continual restoration to the Inorganic Universe, during the whole life of Animals, in the heat, light, electricity, still more in the motion, which they develope; and, after their death, in the production of heat and light during the processes of decay. During Animal life, there is a continual restoration to the mineral world, of the carbonic acid, water, and ammonia, which have been appropriated by Plants; and it will hereafter appear that the amount thus given-off by the animal organism bears a close correspondence, on the one hand, with its degree of vital activity, as shown in the amount of heat and motion which it generates, and, on the other, with the amount of the organic compounds which it consumes as food. So that, on the whole, there is strong reason to believe that the entire amount of force (as of material) received by an animal during a given period, is given-back by it during that period, provided that its condition at the end of the term be the same as it was at first; and further, that all the force (like the material) which has been expended in the building-up of the organism, is given back by its decay after death.*

4. *Of Degeneration and Death.*

63. We have seen that the general history of the phenomena of Life is fully conformable with the view, that the Vital properties of a tissue (that is, the properties in virtue of which the forces that act upon it are caused to manifest themselves in Vital action,) are dependent upon that state of combination and arrangement, which is termed Organization. As long as each tissue retains its normal or regular constitution, renovated by the actions of absorption and deposition through which that constitution is preserved, and surrounded by those other conditions which a living system alone can afford, so long, we have reason to believe, it will retain its vital properties,—and no longer. And just as we have no evidence of the existence of vital properties in any other form of matter than that which we call organized, so have we no reason to believe that organized matter can retain its regular constitution, and be subjected to the appropriate forces, without exhibiting vital actions. The advance of pathological science renders it every day more pro-

* The whole of this subject is more fully developed in the Author's Mem on "The Mutual Relations of the Vital and Physical Forces," contained the Philosophical Transactions for 1850.

bable (indeed the probability may now be said to amount to almost positive certainty), that derangement in *function*,—in other words, an imperfect or irregular *action*,—always results, either from some change of structure or composition in the tissue itself, or from some corresponding change in the forces by which the properties of the organ are called into action. Thus, when a Muscle has been long disused, it can scarcely be excited to contraction by the usual stimulus, or may even be altogether powerless; and minute examination of its structure shows it to have undergone a change which is obvious to the microscope, though it may not be perceptible to the unaided eye, and which results from imperfect nutrition. Or, again, convulsive or irregular actions of the Nervous system may be produced, not by any change in its own composition, but by the presence of various stimulating substances in the blood, although their amount be so small that they can scarcely be recognized.

64. As there is a constant tendency, in the Animal tissues more especially, to spontaneous decay, so must the maintenance of their vital properties depend upon their continual regeneration by the nutritive operations. Hence we have no difficulty in accounting for the Death of the whole system, on the cessation or serious disturbance of any one important function; for any such check or change must suspend or disorder the nutrient processes, in such a degree that they can no longer maintain the normal constitution of the several tissues. But as there is a great variety in the rapidity of the decomposition of the tissues, when the act of nutrition is suspended, so do we witness a corresponding variety in the duration of their vital properties, after that permanent severance of the chain of functions, which is distinguished as *somatic* death,—*i. e.*, the death of the *body* as a whole. It is by the Circulation of the Blood, that the connection of the different functions is essentially maintained; that fluid being not only the material for the nutrition of the tissues, but in many cases supplying also the stimulus to their activity. Hence with the permanent cessation of the Circulation, *somatic* death must be regarded as taking place.

65. Yet after this, we observe that vitality lingers in the tissues; and that it departs from them only as they lose their proper composition. Thus we find that, although the Nervous *centres* cannot *originate* the stimulus necessary to produce Muscular contraction, after the Circulation has ceased,—yet the Nervous *fibres* can *convey* such a stimulus, long after somatic death; so that contractions may be excited in muscles, by the application of galvanism, or of mechanical or chemical stimulants, to the trunks that supply them. The *molecular* death of the Nervous tissue, therefore, has not yet taken place. After a time, however, this power is lost; the tissue no longer exhibits its distinguishing vital properties; and incipient decomposition and change of structure manifest themselves. Yet

for some time after this, the Muscular tissue, especially in a cold-blooded animal, continues to possess its peculiar contractility; for contractions may be excited in it, by stimuli directly applied to itself, long after the nerves have ceased to convey their influence. Sometimes, indeed, the contractility of muscle endures, until changes in its structure and composition become evident to the senses; thus the heart of a Sturgeon, removed from the body, and hung-up to dry, has been known to continue alternately contracting and dilating, until the movement produced a crackling noise, in consequence of the dryness of the texture. Again. there is evidence, that various processes of nutrition and secretion may go on, for some time after somatic death, and even after the removal of the organs from the body, provided that a sufficient quantity of blood remain in them; and the blood itself retains its vitality, so as not to coagulate, whilst contained in the vessels of tissues still living.

66. Hence it is, that parts which have been *completely* separated from the body may often be reunited with it, if they were previously in a healthy state, and too much time have not elapsed; thus, there are many cases on record, in which fingers, toes, noses, or ears, that have been accidentally chopped-off, have been made to adhere and grow as before, by bringing the cut surfaces into contact, even some hours after their severance. It is evident, then, that the parts so severed cannot have lost their vitality; since no treatment could produce union between a dead mass and a living body. And we are fully justified in assuming, that, in cases where attempts at such reunion have not been successful, the death of the separated part has resulted from the too-prolonged interruption of its regular nutritive operations, whereby such chemical and physical changes have taken-place in it, as have destroyed the peculiar structure and composition of its several parts.—The ordinary phenomena of Death, therefore, as well as those of Life, bear out the views which have been here advanced.

67. But it has been maintained by those who consider Vitality as something superadded to an Organized Structure, essentially independent of it, and capable of being subtracted from it, that Death frequently takes place under circumstances which leave the organism as it was; so that "the dead body may have all the organization it ever had whilst alive." For such an assumption, there is not the least foundation. In nearly all cases in which death takes-place as a result of disease, the connection between changes of structure and composition, either in the tissues or in the blood, and such a loss of the vital properties of some part or organ as is sufficient to bring the Circulation to a stand, is so palpable as to require no proof; and in by far the greater majority of cases in which it is not at once obvious, a more careful scrutiny will reveal it. It must be confessed on both sides, that our means of investigation, and our knowledge of the normal structure and composition

of the tissues and the blood, are not yet sufficient to enable us to detect minute shades of alteration, nor to assert what extent of change is inconsistent with the continuance of life. But as no one has yet shown, by the careful and exact microscopical and chemical examination of the solids and fluids of a dead body, that it has all the organization it had whilst alive, the assertion above quoted is totally unwarranted by experience, and is contradicted by all our positive knowledge of the matter. (See § 184.)

68. But it has been urged, that Death may result from the sudden operation of some agency of an *inmaterial* character, which leaves no trace behind it,—such as a powerful electric shock, or a violent mental emotion. Here, too, the argument entirely fails. It is *impossible* that a powerful electric shock could be transmitted through a mass like the animal body, composed of elements in such a loose state of combination that they are always undergoing decomposition, without producing important *chemical* changes in it; and its imperfect conducting power renders it equally liable to *physical* disturbances. As a matter of fact it has been noticed, that the bodies of animals killed by electricity pass into decomposition with unusual rapidity, showing that the ordinary chemical affinities of their components have received a powerful stimulus; and it has also been ascertained, that when eggs in process of development have had their vitality destroyed by an Electric shock, the minute vessels of the *vascular area* (§ 551) have been ruptured.—Nor is it more difficult to explain the immediate cause of death, as a result of Mental emotion. In some cases, an obvious physical change has been produced, by the too violent action of the heart, the movements of which are stimulated by the emotion; thus, even in a healthy person, rupture of the heart or aorta has been known to take place,—an occurrence to which those affected by previous disease of that organ are much more liable. Where there is *any* disorder in the heart's action, resulting from thickened valves, narrowed orifices, &c., the physical influence of mental emotion can be easily accounted for. But it must be admitted that cases have occurred, in which no such explanation can be offered; sudden death having taken place without any perceptible structural cause. We are not obliged, however, for an explanation of even these cases, to have recourse to any hypothesis which is not borne-out by ample analogy. For it is well known that mental emotions, acting through the nervous force, exert a powerful influence over the composition of the *fluids* of the body, and are capable of *instantaneously* altering these. Thus in many human beings, and still more in the lower animals, alarm or agitation will occasion the immediate disengagement of powerfully-odorous secretions, which must have resulted from new combinations suddenly formed; and a fit of passion may immediately occasion such a change in the milk of a nurse, as renders it a rank poison to the infant. There is no reason to doubt, therefore, that

the blood itself may undergo changes of analogous character from the same cause; and that it may become a violent poison to the individual himself, instead of being the source of wholesome nutriment, and the stimulus to vital activity.

69. But the effect of Electricity, of mental Emotion, or even of Mechanical force, may be exerted more *dynamically* than organically; destroying the Vital powers, by antagonizing the forces that produce them, without occasioning any perceptible *material* change. This, in fact, we see in the state of prostration or 'shock,' induced by sudden and violent impressions of almost any description, especially those which have a direct influence upon the Nervous System.

5. *General Summary.*

70. To conclude, then;—we only know of *Life*, as exhibited by an Organized structure, when subjected to the operation of certain *forces* which call it into activity; and we only know of *Vitality*, or the state or endowment of the being which exhibits that action, as conjoined with that particular aggregation and composition which we term *Organization*. We have seen that the act of Organization, and the consequent development of peculiar properties in the tissues which are produced by it, can only be attributed to the vital force of a pre-existing organism; and hence it is, that whilst the operation of Physical forces upon an organized body gives rise to vital phenomena, no such phenomena can be manifested as the result of their action upon any kind of inorganic matter. It is, in fact, the *speciality* of the material instrument thus furnishing the medium of the change in their *modus operandi*, which establishes, and must ever maintain, a well-marked boundary-line between the Physical and the Vital forces. According to the views here propounded, the Vital force is as different from Heat or Electricity, as these are from each other; but just as Heat, acting under certain peculiar conditions, is capable of transformation into Electricity, whilst Electricity is capable, under certain other conditions, of being metamorphosed into Heat, so may either of these forces, acting under conditions which an Organized fabric alone can supply, be converted into Vital force, whilst, in their turn, they may be generated by Vital force.

71. Starting, then, with the abstract notion of one general Force, we might say that this Power, operating through Inorganic matter, manifests itself in those phenomena which we call electrical, magnetical, chemical, thermical, optical, or mechanical; the agents immediately concerned in these being so connected by the relation of reciprocal agency, or 'correlation,' that we must regard them as fundamentally the same. But the very same Force or Power, when directed through Organized structures, effects the operations of growth, development, metamorphosis, and the like; and is

further transformed, through the instrumentality of the structures thus generated, into nervous agency and muscular power. If we only knew of Heat, for example, as it acts upon the organized creation, the peculiarities of its operation upon inorganic matter would seem no less strange to the physiologist, than the effects here attributed to it may appear to those who are only accustomed to contemplate the physical phenomena to which it gives rise.—Of the existence of Force or Power, we can give no other account than by referring it, as we are led by our own consciousness to do, to the exertion of a Will; and this unity among the Forces of Nature is the strongest possible indication of the Unity of the Will of which they are the expressions. And further, the constancy of the actions which result from them, when the conditions are the same, —that is, their conformity to a fixed plan, or (in the language commonly employed) their subordination to *laws*,—indicates the constancy and unchangeableness of the Divine Will, as well as the Infinity of that Wisdom by which the plan was at first arranged with such perfection, as to require no departure from it, in order to produce the most complete harmony in its results.

72. So also, if we endeavour to assign a cause for the existence of a cell-germ, we are led at first to fix upon the vital operations of the parental organism by which it was produced; and for these we can assign no other cause than the peculiar endowments of *its* original germ, brought into activity by the forces which have operated upon it. Thus we are obliged to go backwards in idea from one generation to another; and when at last brought to a stand by the origin of the race, we are obliged to rest in the Divine Will as the source of those wonderful properties, by which the first germ developed the first organism of that race from materials previously unorganized, this organism producing a second germ, the second germ a second organism, and so on without limit, by the uniform repetition of the same processes. Yet we are not to suppose that the *continuation* of the race is really in any way less dependent upon the Will of the Creator, than the *origin* of it. For whilst Science leads us to discard the idea that the Deity is continually *interfering*, to change the working of the system He has made,—since it everywhere presents us with the idea of uniformity in the plan, and of constancy in the execution of it,—it equally discourages the notion entertained by some, that the creation of matter, endowed with certain properties, and therefore subject to certain actions, was the *final* act of the Deity, as far as the present system of things is concerned, instead of being the *mere commencement* of His operations. If it be admitted that matter owes its origin and properties to the Deity, or in other words, that its *first existence* was but an expression of the Divine Will, what is its *continual existence*, but a continued operation of the same Will? To suppose that it could continue to exist, and to perform its

various actions, *by itself*, is at once to assume the property of *self-existence* as belonging to matter, and thus to do away with the necessity of a Creator altogether ;—a conclusion at which it may be safely affirmed that no ordinarily-constituted Man can arrive, who reasons upon the indications of Mind in the phenomena of Nature, in the same way as he does in regard to the creations of Human Art.

CHAPTER II.

OF THE EXTERNAL CONDITIONS OF VITAL ACTIVITY.

73. It has been shown in the preceding Chapter, that the most general conditions of Vital phenomena are two-fold ;—one set being supplied by the *organized structure*, which is endowed (in virtue of its organization) with certain peculiar properties, but which is inert so long as it is altogether secluded from the influence of external agents ;—whilst the other is derived from external sources, and consists in a supply of those *materials* of which the organized structure is built up, and in the operation of those *forces* by which the organism is made to appropriate those materials which are the sources of its peculiar powers. We might thus, in a rough and rude way it is true, compare the living body to a set of machinery adapted to convert cotton from the raw material into a woven fabric. Each portion of the machinery does its own special work, in virtue of its peculiar construction ; *e. g.* one part cards, another spins, and a third weaves ; but their actions are closely related and even mutually dependent. Further, their operations all result from one and the same force or power ; and their products may consequently be regarded as the expressions or manifestations of that Force, which acts through the different portions of the mechanism, each in its own peculiar mode. Now such a machine can produce no result, without the concurrence of these conditions ; namely, the perfectly-constructed *organism* (for so in the wide sense of the term it may be designated), a supply of the raw *material* on which it is to operate, and an adequate *moving power*. And it is to be observed, that the amount of its product will depend rather upon the *power*, than upon the *material* supplied ; for whilst its activity cannot be increased by any augmentation in the quantity of the material, beyond that amount which it has power to employ, it can be promoted by a more energetic application of the force, as well as retarded by its diminution ; the amount of material appropriated being increased or diminished accordingly.

standard, than to the actual degree of heat or cold in operation. Yet the first of these individuals might be gradually habituated to live in the same temperature with the second; and to require the same amount of further depression for the induction of torpidity. (See § 132.)

78. It is a very curious fact, that, whilst the lower classes of living beings are more capable than the higher of bearing the deprivation of these Vital stimuli, they are at the same time more liable to alterations in their own structure and development, in consequence of variations in the intensity of their agency, or from other causes external to themselves. Thus the *forms* of the lower tribes of Plants and Animals are liable to be greatly affected by the conditions under which they grow; and these especially modify their degree of development. It seems as if the formative power were less vigorous in the lower, than in the higher classes; so that the mode in which it manifests itself in the former is more dependent upon external influences; whilst in the latter it either predominates over them, causing the regular actions to be performed, or gives-way altogether.—The same principle applies to the early condition of the higher organisms; their embryos, like those beings of permanently low type which they resemble in degree of development, being liable to be affected by modifying influences, which the perfect beings of the same kind are able to resist.

1. *Of Light, as a Condition of Vital Activity.*

79. The importance of this agent, not only to the Vegetable but also to the Animal World, is not in general sufficiently estimated. Under its influence alone can that first process be accomplished, by which Inorganic matter is transformed into an Organic compound, adapted by its nature and properties to form part of the organized fabric. The following is an example of the simplest phenomenon of this kind; and it demonstrates the influence of Light the more clearly on account of that simplicity. "If we expose some spring-water to the sunshine, though it may have been clear and transparent at first, it presently begins to assume a greenish tint; and, after a while, flocks of green matter collect on the sides of the vessel in which it is contained. On these flocks, whenever the sun is shining, bubbles of gas may be seen, which, if collected, prove to be a mixture of oxygen and nitrogen, the proportion of the two being variable. Meanwhile the green matter rapidly grows; its new parts, as they are developed, being all day long covered with air-bells, which disappear as soon as the sun has set. If these observations be made upon a stream of water, the current of which runs slowly, it will be discovered that the green matter serves as food for thousands of aquatic Insects, which make their habitations in it. These insects are endowed with powers of rapid locomotion,

and possess a highly-organized structure; in their turn they fall a prey to the Fishes which frequent such streams."* Such is the general succession of nutritive actions in the Organized Creation. The highest Animal is either directly dependent upon the Vegetable Kingdom for the materials of its fabric, or it is furnished with these by some other Animal, this again (it may be) by another, and so on; the last in the series being *always* necessitated to find its support in the Vegetable kingdom, since the Animal does not possess the power of causing the Inorganic elements to unite into even the simplest Organic compound. This power is possessed, in a high degree by Plants; but it can only be exercised under the influence of *Light*.—We shall now examine, more in detail, the conditions of this influence, both in the instance just quoted, and in others drawn from the actions of higher Vegetable organisms.

80. The "green matter of Priestley" (as it is commonly called), which makes its appearance when water of average purity is submitted to the action of the Sun's light, and which also presents itself on the surface of walls and rocks that are constantly kept damp, is now known by Botanists to consist of *cells* in various stages of development; some of them constituting simple forms of vegetation which are complete in themselves (Fig. 143), whilst others are the early states of plants somewhat more elevated in the scale (Fig. 144). That these cells all originate from definite germs, and not in a mere combination of inorganic elements, appears not only from general considerations, but also from the fact that, if measures be taken to free the water entirely from any possible infusion of organic matter, and to admit into contact with it such air alone as has undergone a similar purification, no green flocks make their appearance, under the prolonged influence of the strongest sunlight. We find, then, that the presence of a germ is one of the conditions indispensable to the chemical transformation in question.—It may be asked how it can be certainly ascertained that *light*, and not *heat*, is the essential condition of this process; seeing that the two agents are combined in the solar beam. To this it may be replied, that a certain moderate amount of heat is undoubtedly necessary; but that no degree of heat without light will be effectual in producing the change, as is easily proved by exposing the water to warmth in a dark place. Moreover, when a certain measure of light is afforded, variations in the amount of heat make very little difference; whilst, as we shall presently see, under the same degree of heat, the amount of the change is directly proportional to the intensity of the light. Although, therefore, heat furnishes an essential condition, it cannot be questioned that *light* is the chief agent in the process by which the Vegetable germ brings into union the elements to be employed in the development of its own fabric.

* Prof. Draper, on the Forces which produce the Organization of Plants; p. 15.

81. The next question is,—What are these elements, and whence are they obtained? All water that is long exposed to the atmosphere, absorbs from it a certain amount of its constituent gases; but these do not enter it in the proportions in which they are contained in the atmosphere itself; their relative quantities, in a given measure of water, being proportional to the facility with which they are respectively absorbed by the liquid. Thus, Carbonic acid is most readily absorbable, Oxygen next, and Nitrogen least so. From the experiments of Prof. Draper it would appear, that, notwithstanding the very small proportion of carbonic acid contained in the atmosphere (usually not more than 1-5000th part), it forms as much as 29 per cent. of the whole amount of air expelled from water by boiling. Of the residue, one-third consists of oxygen, and the remaining two-thirds of nitrogen; so that the proportion of the oxygen to the nitrogen is as *one* to *two*, instead of being *one* to *four*, as in atmospheric air. The absolute quantity of this water-gas, contained in any measure of water, is subject to variation with the temperature; the quantity being diminished as the temperature rises.—Now when water thus impregnated with carbonic acid, oxygen, and nitrogen, and containing the germs of aquatic plants, is exposed to the sun's light, a development of vegetable structure takes place, indicated by the green flocculent appearance noticed already. If the changes now occurring in the water be investigated, we find that the carbonic acid is diminishing in amount; and that oxygen is being evolved. The growing mass increases in volume and weight; and after a time exhausts the whole carbonic acid originally contained in the water. If it be then prevented from receiving an additional supply, the process stops; but, as conducted naturally, there is a free exposure to the atmosphere, through which carbonic acid is diffused; and hence, as fast as this gas is removed by decomposition, it is restored by absorption.—The same holds good, also, with regard to the ammonia of the atmosphere, which, notwithstanding its very minute proportion, supplies the nitrogen required for the production of the azotized compounds of plants.

82. Here then are the conditions and materials; what is the result? By the conjoint action of light and of a vegetable cell-germ, with a moderate degree of heat, upon carbonic acid, ammonia, and water, those principal components of the vegetable fabric are produced, which consist of carbon united with the elements of water. Whether this union is really as simple and direct as is implied by this expression, or whether the same proportions of oxygen, hydrogen, and carbon are united in a different form, is not a matter of consequence to the present inquiry; the general fact being, that by the decomposition of the carbonic acid, oxygen is set-free, and carbon is made to unite with the elements of water; so as to form organic compounds, which are appropriated by the Vegetable organism as materials for its growth.—How far Light is also concerned in the

production of the albuminous compounds which are generated by Plants, not merely for the use of Animals, but also as part of the material of their own growth, has not been yet ascertained; but it is probable that these are not the less dependent upon its agency for their formation, since they are formed under the same circumstances with the preceding.

83. The process whose conditions we have thus examined, is carried-on in the individual cells of which the highest and most complex Plants are composed, precisely as in those which constitute the entire organisms of the lowest. Thus if a few garden-seeds of any kind be sown in a flower-pot, and be caused to germinate in a dark room, it will soon be perceived that although they can grow for a time without the influence of light, that time is limited; the *weight* of their solid contents diminishes, although their *bulk* may increase by the absorption of water; their young leaves, if any should be put-forth, are of a yellow or gray-white colour, and they soon fade-away and die. But if these plants are brought out sufficiently soon into the bright sunlight, they speedily begin to turn green; they unfold their leaves, and evolve their different parts in a natural way; and the proportion of their solid contents goes on increasing from day to day. If the fabric be then subjected to chemical analysis, it is found to contain oxygen, hydrogen, carbon, and nitrogen, united in various proportions, so as to form compounds that differ in the various species; though some, -such as gum, starch, cellulose, and albuminous matter,--are the same in all. If the plants be made to grow in closed glass vessels, under such circumstances that an examination can be accurately made as to the changes they are impressing on the atmosphere, it is discovered that they are constantly decomposing its carbonic acid, - appropriating its carbon, and setting free its oxygen, so long as they are exposed to the influence of sunshine or bright daylight. They also appropriate a part of the minute quantity of ammonia which is diffused through the atmosphere; extracting its nitrogen to employ it in the production of their azotized compounds. It is capable of being demonstrated by experiment, that these changes are confined to the *green* surfaces of plants, and therefore to the leaves or leaf-like organs, to the young shoots, and to the stems of herbaceous plants, or of those in which (as in the Cactus tribe) the leaves are wanting and the enlarged succulent stem supplies their place. When these surfaces cease to become green, the decomposing action also ceases; carbon is no longer fixed and oxygen set-free; but, on the contrary, carbonic acid is exhaled: this is the case when the leaves change colour, previously to their fall, in the autumn. The compounds which are thus generated in the green surfaces, are conveyed, by the circulation of the sap, to the remote parts of the fabric, and become the materials of their nutrition; and thus the green cells of the leaves have exactly the same function, in ministering to the

growth of the fabric of the largest tree, which the green cells of the humble Protophyte perform in regard to themselves alone.

84. It has been already mentioned (§ 35) that the decay which is always taking-place in the softer Vegetable structures, gives-rise to a continual production of carbonic acid, even in the living plant; this process, which must be regarded as a true Respiration, is effected, as in Animals, by the union of the carbon of the Plant with oxygen derived from the atmosphere; and it is carried-on, not by the green parts only, but also, perhaps chiefly, by the darker surfaces. Being antagonized during the day by the converse change just described, it can only be made sensible, by placing the plants for a time in an atmosphere in which no carbonic acid previously existed; and it will then be found that, even in full daylight, a certain amount of that gas is exhaled. The fact, however, becomes much more obvious at night, or in darkness; since the decomposition of the surrounding carbonic acid by the green surfaces is then completely at a stand, and the full effect of the respiratory process is seen. Moreover, when a plant becomes unhealthy from too long confinement in a limited atmosphere, it begins to exhale more carbonic acid than it decomposes; and the same is the case, as just now stated, in regard to leaves that have nearly reached the term of their lives. It does not admit of question, however, that, under ordinary circumstances, nearly the whole carbon of a slow-growing plant is derived from the carbonic acid of the atmosphere; either directly through the leaves, or indirectly by absorption through the roots; and that there must be a vast surplus, therefore, of the carbonic acid decomposed, over that which is exhaled, during the whole life of the tree,—that surplus being in fact represented by the total amount of carbon contained in its tissues.

85. It is probable that the minute amount of Carbonic Acid at present contained in the atmosphere, is as much as could be beneficially supplied to Plants, under the average amount of light to which they are subjected, over the whole globe, and throughout the year. Yet it has been found by experiment, that, under the influence of strong sunlight, an atmosphere containing as much as 7 or 8 per cent. of carbonic acid may be not merely tolerated by Plants, but may be positively beneficial to them, producing a great acceleration in their growth: as soon as the light is withdrawn, however, this excess acts upon them most injuriously, causing them speedily to become unhealthy, and altogether destroying their vitality, if they be long subjected to it. Under more cloudless skies than ours, the continual supply of a larger quantity of carbonic acid than our atmosphere contains, is found to be quite compatible with healthy vegetation; especially in the case of Cryptogamic plants, which (as will be presently shown) require a less amount of light than do those of a higher kind. Thus in the lake Solfatara in Italy, an unusual supply of carbonic acid is afforded by the constant escape of that gas

from fissures in the bed of the lake, with a violence that gives to the water an appearance of ebullition; and on its surface there are numerous floating islands, which consist almost entirely of Confervæ and other simple cellular plants, growing most luxuriantly on this rich pabulum. And it has been remarked that the vegetation around the springs in the valley of Gottingen, which abound in carbonic acid, is very rich and luxuriant; appearing several weeks earlier in the spring, and continuing much later in the autumn, than at other spots in the same district. Many circumstances lead to the belief, that at former epochs in the Earth's history, the atmosphere was much more highly charged with carbonic acid than at present; and that to this circumstance, in conjunction with a more intense and constant influence of light and heat, we are to attribute that extraordinary luxuriance of the vegetation of those periods, of which we have most abundant evidence, not only in the vast beds of disintegrated vegetable matter—Coal—that are of such value to Man, but also in the remains which have been more perfectly preserved to us, and which indicate that not only the general forest-mass, but many of the individual forms, attained a degree of development which can scarcely now be paralleled even between the Tropics.

86. Various experiments have been recently made, with the view of determining more precisely the conditions under which Light acts, in producing the chemical changes that have been now discussed. These experiments for the most part agree in the very interesting result, that the amount of carbonic acid decomposed by plants subjected to the differently-coloured rays of the solar spectrum, but otherwise placed in similar circumstances, varies with the *illuminating* power of the rays, and not with their *heating* or their *chemical* power. The method adopted by Prof. Draper, which seems altogether the most satisfactory, consisted in exposing leaves of grass, in tubes filled with water which had been saturated with carbonic acid (after the expulsion of the previously-dissolved air by boiling), to the influence of the different rays of the solar spectrum, dispersed by a prism; these were kept motionless upon the tubes, for a sufficient length of time to produce an active decomposition of the gas, in the tubes which were most favourably influenced by the solar beams; and the relative quantities of the oxygen set-free were then measured. It was then evident that the action had been almost entirely confined to two of the tubes, one of them being placed in the red and orange part of the spectrum, and the other in the yellow and green. The quantity of carbonic acid decomposed by the plant in the latter of these, was to that decomposed in the former, in the ratio of *nine* to *five;* the quantity found in the tube that had been placed in the green and blue portion of the spectrum, would not amount, in the same proportion, to *one;* and in the other tubes, it was either absolutely nothing, or extremely minute. Hence it is obvious that the yellow ray, verging into orange on one

side, and into green on the other, is the situation of the greatest exciting power possessed by light on this most important function of plants; and as this coincides with the seat of the greatest illuminating power of the spectrum, it can scarcely be doubted that *light* is the agent here concerned; more especially as the place of greatest *heat* is in the *red* ray, and that of greatest chemical power is in the *blue*, both of which rays were found to be quite inert in the experiment just quoted.—It must not be supposed from this experiment, however, that the yellow ray, and those immediately adjoining it, are the *only* sources of this power in the Solar spectrum; since it proves no more than that, when the leaves were exposed to an atmosphere loaded with carbonic acid, they could only decompose it under the influence of these rays. It is certain from other experiments, that plants will grow, in an ordinary atmosphere, under rays of different colours; and it appears that the amount of carbon they severally fix, bears a constant proportion to the illuminating powers of the respective rays.

87. Although this fixation of carbon by the decomposition of carbonic acid (with which it is probable that the decomposition of ammonia is intimately associated), is the most universally-dependent, of all the processes of the Vegetable economy, upon the influence of Light, yet it is not the only one, especially among the higher Plants, to which that influence supplies an important condition. Of the whole quantity of moisture imbibed by the roots and contained in the ascending sap, a large proportion is *exhaled* again by the leaves; a small part only being retained (together with the substances previously dissolved in the whole) to form part of the fabric. Now upon the rapidity of this exhalation, depends the rapidity of the absorption; for the roots will not continue to take-up more than a very limited amount of fluid, when it is not discharged again from the opposite extremity (so to speak) of the stem. The loss of fluid by the leaves appears to be a simple process of evaporation, depending in great part upon the temperature and dryness of the surrounding air; this evaporation, however, does not take-place solely, or even chiefly, from the external surface of the leaves, but from the walls of the passages which are channelled-out in their interior. Into this complex labyrinth, the outer air finds its way through orifices in the cuticle, which are termed *stomata*; and through these it comes-forth again, charged with a large amount of vapour communicated to it by the extensive moist surface with which it comes into contact in the interior of the leaf. Now the stomata are bounded by two or more cells, in such a manner that they can be opened or closed by changes in the form of these; and this alteration is regulated by the amount of Light to which the leaves are subjected. When the stomata are opened under the influence of light, the external air is freely admitted to the extended surface of moist tissue within the leaf, and a rapid loss of fluid is

the result; more especially if the temperature be high, and the atmosphere in a dry state. On the other hand, if the stomata be closed, the only loss of fluid that can take-place from the internal tissue of the leaves, is through the cuticle; the organization of which seems destined to enable it to resist evaporation, so that the exhalation is almost entirely checked.—The influence of Light upon this important function is easily shown by experiment. If a plant which is actively transpiring and absorbing under a strong sunshine, be carried into a dark room, both these operations are almost immediately checked, even though the surrounding temperature be higher than that to which the plant was previously exposed.

88. The effect of the complete and continued withdrawal of Light from a growing plant, is to produce an *etiolation* or blanching of its green surfaces; a loss of weight of the solid parts, owing to the continued disengagement of carbon from its tissues, unbalanced by the fixation of that element from the atmosphere; a dropsical distension of the tissues, in consequence of the continued absorption of water, which is not got-rid-of by exhalation; a want of power to form its peculiar secretions, or even to generate new tissues, after the materials previously stored-up have been exhausted; in fine, a cessation of all the operations most necessary to the preservation of the vitality of the structure, of which cessation its death is the inevitable result. A partial withdrawal of the influence of light, however, is frequently used by the Cultivator, as a means of giving an esculent character to certain plants which would be otherwise altogether uneatable; for in this manner their tissues are rendered more succulent and less 'stringy,' whilst their peculiar secretions are formed in diminished amount, and communicate an agreeable flavour instead of an unwholesome rankness of taste.

89. There is one period in the life of the Flowering-plant, however, in which the influence of Light is rather injurious than beneficial; this is during the first part of the process of germination of seeds, which is decidedly retarded by its agency. Yet there is here no exception to the general rule; since the decomposition of the carbonic acid of the atmosphere, and the fixation of carbon in the tissues, do not constitute a part of the operation. On the contrary, the embryo being nourished, like an animal, by organic compounds previously elaborated and stored-up in the seed, the chemical changes which take-place in them involve the opposite action,—the extrication of carbon, which is converted into carbonic acid by uniting with the oxygen of the atmosphere. It is obvious, then, why light should not only be useless, but even prejudicial to this process; since it tends to fix in the tissues the carbon which ought to be thrown-off. As soon, however, as the cotyledons or seed-leaves are unfolded, the influence of light upon them becomes as important, as it is on the ordinary leaves at a subsequent time;

their surfaces become green, and the fixation of carbon from the atmosphere commences. Up to that period, the young plant diminishes day by day (like a plant that is undergoing etiolation) in the weight of its solid contents, although its bulk increases by the absorption of water. From the time, however, that its cotyledons begin to act upon the air, under the influence of light, the quantity of solid matter begins to augment; and its augmentation subsequently continues, at a rate proportional to the amount of green surface exposed, and the degree of light to which it is subjected.

90. The influence of Light upon the direction of the growing parts of Plants, upon the opening and closing of flowers, &c., is probably due to its share in the operations already detailed. Thus the green parts of Plants, or those which effect the decomposition of carbonic acid (such as the leaves and stems), have a tendency to grow towards the light; whilst the roots, through whose dark surfaces carbonic acid is thrown-out by respiration, have an equal tendency to avoid it. That the first direction of the stems and roots of plants is very much influenced in this manner, appears from the fact, that, by reflecting light upon germinating seeds, in such a manner that it shall only fall upon them from below, the stems are caused to direct themselves downwards, whilst the roots grow upwards.—There can be no doubt, however, that Light has also a more direct influence on the development of particular organs in certain Vegetables. Thus when the *gemmules** of the *Marchantia polymorpha* (one of the *Hepaticæ* or Liverworts) are in process of development, it has been shown by repeated experiments, that stomata are formed on the side exposed to the light, and that roots grow from the lower surface; and that it is a matter of indifference *which* side of the little disk is at first turned upwards, since each has the power of developing either stomata or roots, according to the influence it receives. After the tendency to the formation of these organs has once been given, however, by the sufficiently-prolonged influence of light upon one side, and of darkness and moisture upon the other, any attempt to alter it is found to be vain; for if the surfaces be then inverted, they are soon restored to their original aspects by the twisting growth of the plant.

91. The same amount of this agent is not requisite or desirable for all Plants; and we find in the different *habitats* which are characteristic of different species, even amongst our native plants, that the amount congenial to each varies considerably. Generally speaking, the succulent thick-leaved Plants require the largest

* These gemmules are analogous to the *buds* of higher plants; and they consist of little collections of cells, having the form of flat disks, which are at first attached by footstalks arising from the bottom of little basket-shaped conceptacles evolved from the surface of the fronds of the parent-plant, but afterwards fall-off and are developed into new fronds.

amount of light; their stomata are few in number, and its full influence is requisite to induce sufficient activity in their exhaling process; accordingly we find them growing, for the most part, in exposed situations, where there is nothing to interfere with the free action of the solar rays. On the other hand, plants with thinner and more delicate leaves, in which the exhaling process is easily excited to an excessive amount, evidently find a congenial home in more sheltered situations; and there are some which can only develope themselves in full luxuriance, in the deep shades of a plantation or a forest. By a further adaptation of the same kind, some species of Plants are enabled to live and acquire their green colour, under an amount of deprivation which would be fatal to most others; thus in the mines of Freyberg, in which the quantity of light admitted must be almost infinitesimally small, Humboldt met with Flowering-plants of various species; and mustard and cress have been raised in the dark abysses of the collieries of this country.

92. Generally speaking, however, the Cryptogamia would seem to be better adapted than Flowering-plants, to carry on their vegetating processes under a low or very moderate amount of this agency. Thus Humboldt found a species of Sea-weed near the Canaries, which possessed a bright grass-green hue, although it had grown at a depth of 190 feet in the sea, where, according to computation, it could have received only 1-1500th part of the solar rays that would have fallen upon it at the surface of the ocean. Many Ferns, Mosses, and Lichens seem as if they avoided the light, choosing the northern rather than the southern sides of hedges, buildings, &c., for their residence; so that the former often present a luxuriant growth of Cryptogamic vegetation, whilst the latter are comparatively bare. It must not be supposed, however, that they avoid light altogether, but only what is to them an excessive degree of it. The avoidance of light seems to be much stronger in the Fungi, which grow most luxuriantly in very dark situations; and the reason of this is probably to be found in the fact, that, like the germinating seed (§ 89), they form rather than decompose carbonic acid; their food being supplied to them from the decaying substances on which they grow; and the rapid changes in their tissues giving rise to a high amount of Respiration,—a change exactly the converse of that on which, as we have seen, Light exerts such a remarkable power.

93. In regard to the agency of Light upon the functions of Animals, comparatively little is certainly known. It is evident that the influence it exerts on those chemical processes, which constitute the first stage of Vegetable nutrition, can have scarcely any place in Animals; because *they* do not perform any such acts of combination, but make use of the products already prepared for them by Plants. Hence we do not find that the *surface* of Animals

undergoes that extension, for the purpose of being exposed to the solar rays, which is so characteristic a feature in the Vegetable fabric, and is so important in its economy. Still there can be no doubt, that the degree of exposure to light has a great influence upon the *colours* of the Animal surface; and here we seem to have a manifestation of Chemical agency, analogous to that which gives colour to the Vegetable surface. Thus it is a matter of familiar experience, that the influence of light upon the skin of many persons, causes it to become spotted with brown *freckles;* these freckles being aggregations of brown 'pigment-cells,' which either owed their development to the agency of light, or were enabled by that agency to perform a chemical transformation which they could not have otherwise effected. In like manner, the swarthy hue, which many persons acquire in warm climates, is due to a development of dark pigment-cells diffused through the epidermis (§ 229); and an increase of the same kind of action gives-rise to the blackness of the Negro-skin. There can be no doubt that the prolonged influence of light upon one generation after another, tends to give a permanent character to this variety of hue; which will probably be more easily acquired, in proportion to the previously-existing tendency to that change. Thus it is well known that a colony of Portuguese Jews, which settled at Tranquebar about three centuries ago, and which has kept itself distinct from the surrounding tribes, cannot now be distinguished as to colour from the native Hindoos. But it is probable that a similar colony of fair-skinned Saxons would not, in the same time, have acquired anything like the same depth of colour in their skins.

94. It can scarcely be questioned, that the brilliancy of colour which is characteristic of many tribes of animals in tropical climates, especially Birds and Insects, is in great part dependent, like the brightness of the foliage and fruit of the same countries, upon the brightness of the light to which their surfaces are exposed. When birds of warm climates, distinguished by the splendour of their plumage, are reared under an artificial temperature in our own country, it is uniformly observed that they are much longer in acquiring the hues characteristic of the adult; and that these are never so bright, as when they have been produced by the influence of the tropical sun. And it has been also remarked, that if certain Insects (the Cockroach for example), which naturally inhabit dark places, be reared in an *entire* seclusion from light, they grow-up almost as colourless as Plants that are made to vegetate under similar circumstances.

95. There is reason to believe that Light exercises an important influence on certain processes of *development* in Animals, as well as in Plants. Thus, the appearance of Animalcules in infusions of decaying organic matter is much retarded, if the vessel be altogether secluded from it. The rapidity with which the small Entomos-

tracous Crustacea (water-fleas, &c.) of our pools, undergo their transformations, has been found to be much influenced by the amount of light to which they are exposed. And it has been ascertained that, if equal numbers of Silk-worm's eggs be preserved in a dark room, and be exposed to common daylight, a much larger proportion of larvæ are hatched from the latter than from the former.—The most striking proof of the influence of Light on Animal development, however, is afforded by the experiments of Dr. Edwards. He has shown that, if Tadpoles be nourished with proper food, and be exposed to the constantly-renewed contact of water (so that their respiration may be freely carried-on, whilst they remain in their fish-like condition), but be entirely deprived of light, their growth continues, but their metamorphosis into the condition of air-breathing animals is arrested, and they remain in the condition of gigantic tadpoles.—It is interesting to remark, that the *Proteus anguineus*, an animal which closely corresponds in its fully-developed form with the transition-stage between the Tadpole and the Frog, finds a congenial abode in the dark lakes of the caverns of Styria and Carniola, and in the underground passages that connect them; thus showing its adaptation to a condition, which keeps-down to the same standard the development of an animal, that is empowered under other circumstances to advance beyond it. In the same caverns, numerous species of Insects, all of them (like the Proteus) destitute of eyes, have been recently discovered; and that the entire privation of light for many successive generations may have served to prevent the development of their visual organs, seems probable from the fact that has been frequently observed in the Human eye, that if the admission of light to its retinal surface be *entirely* prevented by opacity of the cornea or crystalline lens, the nervous tissue of the retina and optic nerve becomes atrophied, and the whole eye diminishes in size.—Numerous facts, collected from different sources, lead to the belief that the healthy development of the Human body, and the rapidity of its recovery from disease, are greatly influenced by the amount of Light to which it has been exposed. It has been observed, on the one hand, that a remarkable freedom from deformity exists amongst nations who wear very little clothing; whilst, on the other, it appears certain that an unusual tendency to malformation is to be found among persons brought-up in cellars or mines, or in dark and narrow streets. Part of this difference is doubtless owing to the relative purity of the atmosphere in the former case, and the want of ventilation in the latter; but other instances may be cited, in which a marked variation has presented itself, under circumstances otherwise the same. Thus, it has been stated by Sir A. Wylie (who was long at the head of the medical staff in the Russian army), that the cases of disease on the dark side of an extensive barrack at St. Petersburg, have been uniformly, for many years, in the

proportion of three to one, to those on the side exposed to strong light. And in one of the London Hospitals, with a long range of frontage looking nearly due north and south, it has been observed that residence in the south wards is much more conducive to the welfare of the patients, than in those on the north side of the building.

96. These facts being kept in view, it is easy to perceive that there must be differences among the various species of Animals, as among those of Plants, in regard to the degree of light which is congenial to them. Among the lowest tribes, in which no special organs of vision exist, there is evidently a susceptibility to the influence of light, which appears scarcely to deserve the name of 'sensibility,' but which seems rather analogous to that which is manifested by Plants; thus among those Polypes which are not fixed to particular spots, and amongst Animalcules, there are some species which seek the light, and others which shun it. And it appears from various observations upon the depths at which marine animals are found, especially from the extensive series of facts collected by Prof. E. Forbes,* that there are a series of *zones*, so to speak, to be met-with in descending from the surface towards the bottom of the ocean, each of which is characterized by certain species of animals peculiar to itself, whilst other species have a range through two or more of the zones;—the extent of the range of depth, in each species, bearing a close correspondence with the extent of its geographical distribution. Now there can be no doubt, that the restriction of particular species to particular zones is due in great part to the degree of *pressure* of the surrounding medium; but there can be as little doubt, that the variation in the degree of Light also exerts a most important influence, the solar rays in their passage through sea-water being subject to a loss of one-half for every seventeen feet. From the results of Prof. Forbes's researches, it appears that no species of Invertebrated animals habitually live at a greater depth than 300 fathoms; and although Fishes have been captured at a depth of from 500 to 600 fathoms, it is probable that they had strayed from their usual abodes.

2. *Of Heat, as a Condition of Vital Activity.*

97. The most perfectly-organized body, supplied with all the other conditions requisite for its activity, must remain completely inert, if it do not receive a sufficient amount of Heat. The influence which this agent exerts upon Living beings, is far more remarkable than its effects upon Inorganic matter; although the latter are usually more obvious. We are all familiar with its power of pro-

* Report on the Invertebrata of the Ægean Sea, in Transactions of British Association, 1843.

ducing expansion,—with the liquefaction which is the consequence of its application to solids,—with the evaporation which it occasions in liquids,—and with the enormous repulsive force which it generates among the particles of vapours; but it is not until we look deeper than the surface, that we perceive how immediate is the dependence of every action of Life upon this powerful agent. The temporary or permanent loss of vitality, in parts of the body subjected to extreme cold, is a 'glaring instance' of the effect of its withdrawal. This change, however, is not immediate. Its first step is a mere depression of the vitality of the part, involving a partial stagnation of the capillary circulation, diminution of sensibility, and want of muscular power. But the continued action of cold on the surface, not compensated by a sufficient generation of heat within, causes the circulation of the part to be completely suspended; its small vessels contract, so that they become almost emptied of blood; its sensibility and power of movement are destroyed;—in a word, its vital activity is completely suspended. In such a state, a timely but cautious application of warmth may produce the gradual renewal of the circulation, and the restoration of the other powers which are dependent upon that function; but any abrupt change would complete the mischief which the cold has begun; and would altogether destroy, by the violence of the reaction, the vitality which was only suspended, causing the actual *death* of the part. Hence, when the extremities are 'frost-bitten,' nothing can be more injurious than to bring them near a fire; whilst no treatment has been found so safe and effectual, as the rubbing them with snow.

98. The influence of Heat upon Vital activity is attested on a larger scale, by the striking contrast between the dreary barrenness of Polar regions, and the luxuriant richness of Tropical countries, where almost every spot to which moisture is supplied teems with Animal and Vegetable life. And the alternation of Winter and Summer in temperate climates, may be almost said to bring under our own view the opposite conditions of those two extreme cases. The effect of the withdrawal of Heat is most obvious in the Vegetable kingdom; since all its operations are dependent upon a certain supply of that agent; and in no case are Plants possessed of the power of generating that supply within themselves, excepting in certain organs which do not impart it to the rest of the structure. When the temperature of the air falls to the freezing-point, therefore, we find all the operations of the Vegetable economy undergoing a complete suspension; yet a very trifling rise will produce a renewal of them. It is not only in Evergreens, that the vital processes continue to be performed to a certain extent during the winter; for there is abundant evidence that, even in the trunk and branches of trees unclothed with leaves, a circulation of sap takes place, whenever there is even a slight return of warmth. In this

manner, the leaf-buds are gradually prepared during the milder days of winter, so as to be ready to start-forth into full development with the returning steady warmth of spring.

99. The influence of Heat upon Vegetation is easily made apparent by experiment; in fact, experimental illustrations of it, on a large scale, are daily in progress. For the Gardener, by artificial warmth, is not only enabled to rear with success the plants of tropical climates, whose constitution would not bear the chilling influence of our winter;—but he can also, in some degree, invert the order of the seasons, and produce both blossom and fruit from the plants of our own country, when all around seems dead. This process of *forcing*, however, is unfavourable to the health and prolonged existence of the plants subjected to it; since the period of repose which is natural to them, is interrupted; and they are caused, as it were, to live too fast. The same result occurs, when a plant or tree of temperate climates is transported to the tropics. Within a very short period after one crop of leaves has fallen-off, a new one makes its appearance. This goes through all its changes of development and decay more rapidly than it would do in its native clime: and in its turn falls-off, and is speedily succeeded by another. Hence the fruit-trees of this country, transported to the East or West Indies, bear abundant crops of leaves,—three, perhaps, in one year, or five in two years,—but little or no fruit; and the period of their existence is much shortened.

100. As Plants are almost wholly dependent upon the surrounding medium, for the supply of Heat necessary for their growth, many regions must have been devoid of Vegetable life altogether, if there were not a remarkable adaptation, in the wants of different species, to the various degrees of temperature of the habitations prepared for them. Thus the Lichen which serves as the winter food of the Rein-deer, spreads itself over the ground whilst thickly covered with snow; and the beautiful little *Protococcus nivalis*, or 'red snow,' reddens extensive tracts in the arctic regions, where the perpetual frost of the surface scarcely yields to the influence of the solar rays at Midsummer. On the other hand, we see the Cacti and Euphorbiæ attaching themselves to the surface of the most arid rocks of tropical regions, luxuriating, as it would seem, in the full glare of the vertical sun, and laying-up a store of moisture from the periodical rains, of which even a long-continued drought is not sufficient to deprive them. The Orchideous tribe, on the other hand, whose greatest development occurs in the same zone, find their congenial habitation in the depths of the tangled forests, where, with scarcely an inferior amount of heat, they have the advantage of a moister atmosphere, caused by the exhalations of the trees on which they cling. The majestic Tree-Fern, again, reaches its full development in insular situations; where, with a moist atmosphere, it can secure a greater equability of temperature

than is to be met-with in the interior of the vast tropical continents. None of these races can develope themselves elsewhere, to their full extent at least, unless their natural conditions of growth are imitated as far as possible; and in proportion as this imitation can be made complete, in that proportion may the plant of the tropics be successfully reared in temperate regions.

101. There are some examples of the adaptation of particular forms of Vegetable life to extremely high temperatures, which are interesting as showing the extent to which this adaptation may be carried. In hot springs near a river of Louisiana, of the temperature of from 122° to 145°, there have been seen to grow, not merely Confervæ and herbaceous plants, but shrubs and trees; and a hot-spring in the Manilla islands, which raises the thermometer to 187°, has plants flourishing in it, and on its borders. A species of Chara has been found growing and reproducing itself in one of the hot-springs of Iceland, which boiled an egg in four minutes; various Confervæ, &c., have been observed in the boiling-springs of Arabia and the Cape of Good Hope; and at the island of New Amsterdam, there is a mud-spring, which, though hotter than boiling-water, gives-birth to a species of Liverwort.

102. It is, for the most part, among the Cryptogamic tribes,—the Ferns, Mosses, Liverworts, Fungi, and Lichens,—that the greatest power of growing under a low temperature exists; and we accordingly find that the proportion of these to the Phanerogamia or Flowering-plants, increases as we proceed from the Equator towards the Poles. It has been estimated by Humboldt, that, in Tropical regions, the number of species of Cryptogamia is only about *one-tenth* that of the Flowering-plants; in the part of the Temperate zone which lies between Lat. 45° and 52°, the proportion rises to *one-half*; and the relative amount gradually increases as we proceed towards the Poles, until, between Lat. 67° and 70°, the number of species of Cryptogamia *equals* that of the Phanerogamia. Among the Flowering-plants, moreover, the greatest endurance of cold is to be found in those which approach most nearly to the Cryptogamia in the low degree of their development; thus the Glumaceous group of Endogens, including the Grasses, Rushes, and Sedges, which forms about *one-eleventh* of the whole amount of Phanerogamic vegetation in the Tropics, constitutes *one-fourth* of it in the Temperate regions, and *one-third* in the Polar; and the ratio of the Gymnospermic group of Exogens, which chiefly consists of the Pine and Fir tribe, increases in like manner. Still the influence of a high temperature is evident even upon the Cryptogamia and their allies; for it is only under the influence of the light and warmth of tropical climes, that the Ferns,—the highest among the former,—can develope a woody stem, and assume the character of trees; and it is only there that the tall Sugar-Canes and

the gigantic Bamboos, which are but Grasses on a large scale, can flourish.

103. It appears, then, that to every species of Vegetable there is a temperature which is most congenial, from its producing the most favourable influence on its general vital actions. There is a considerable difference between the power of *growing*, and of *flourishing*, at a given temperature. We may lower the heat of a plant to such a degree, as to allow it to continue to live; yet its condition will be unhealthy. It absorbs food from the earth and air, but cannot assimilate and convert it. Its tissue grows, but becomes distended with water, instead of being rendered firm by solid deposits. The usual secretions are not formed; flavour, sweetness, and nutritive matter, are each diminished; and the power of flowering and producing fruit is lost. We see a difference in the amount of heat required for the vegetating processes, even in the various species indigenous to our own climate; thus the common Chickweed and Groundsel evidently grow readily at a temperature but little above the freezing point, whilst the Nettles, Mallows, and other weeds around them, remain torpid. But the difference is much more strongly marked in the vegetation of different climates; showing an evident adaptation of the tribes indigenous to each, to that range of temperature which they will there experience. Instead of being scantily supplied with such of the tropical plants as could support a stunted and precarious life in ungenial climates, the temperate regions are stocked with a multitude of vegetables which appear to be constructed expressly for them; inasmuch as these species can no more flourish at the Equator, than the equatorial species can thrive in the Temperate regions. And such new supplies, adapted to new conditions, recur perpetually as we advance towards the apparently frozen and untenantable regions in the neighbourhood of the Pole. Every zone has its peculiar vegetables; and while we miss some, we find others making their appearance, as if to replace those which are absent.

104. Thus in the countries lying near the Equator, the vegetation consists in great part of dense forests of leafy Evergreen trees, Palms, Bamboos, and Tree-Ferns, bound-together by clustering Orchideæ and strong creepers of various kinds. There are no verdant meadows, such as form the chief beauty of our temperate regions: and the lower orders of Vegetation are extremely rare. It is only in this torrid zone, that Dates, Coffee, Cocoa, Bread-fruit, Bananas, Cinnamon, Cloves, Nutmegs, Pepper, Myrrh, Indigo, Ebony, Logwood, Teak, Sandal-wood, and many others of the vegetable products most highly valued for their flavour, their odour, their colour, or their density, come to full perfection. As we recede from the Equator, we find the leafy Evergreens giving-place to trees with deciduous leaves; rich meadows appear, abounding with tender herbs; the Orchideæ no longer find in the atmosphere, and on the

surface of the trees over which they cluster, a sufficiency of moisture for their support, and the parasitic species are replaced by others which grow from fleshy roots implanted in the soil; but aged trunks are now clothed with Mosses; decayed vegetables are covered with parasitical Fungi; and the waters abound with Confervæ. In the warmer parts of the temperate regions, the Apricot, Citron, Orange, Lemon, Peach, Fig, Vine, Olive, and Pomegranate, the Myrtle, Cedar, Cypress, and Dwarf Palm, find their congenial abode. These give-place, as we pass northwards, to the Apple, the Plum, and the Cherry, the Chestnut, the Oak, the Elm, and the Beech. Going further still, we find that the fruit-trees are unable to flourish, but the timber-trees maintain their ground. Where these last fail, we meet with extensive forests of the various species of Firs; the Dwarf Birches and Willows replace the larger species of the same kind; and even near or within the arctic circle, we find wild flowers of great beauty,—the Mezereon, the yellow and white Water-Lily, and the Globe-flower. Where none of these can flourish, where trees wholly disappear, and scarcely any flowering-plants are to be met-with, an humbler Cryptogamic vegetation still raises its head, in proof that no part of the Globe is altogether unfit for the residence of living beings, and that the empire of Flora has no limit.

105. But distance from the Equator is by no means the only element in the determination of the mean temperature of a particular spot, its height above the level of the sea being equally important; for this produces a variation in the amount of heat derived from the Sun, at least as great as that occasioned by difference of latitude. Thus it is not alone on the summits of Hecla, Mount Blanc, and other mountains of arctic or temperate regions, that we find a coating of perpetual snow; we find a similar covering on the lofty summits of the Himalayan chain, which extends to within a few degrees of the tropic of Cancer; and even on the higher peaks of that part of the ridge of the Andes which lies immediately beneath the Equator. The height of the *snow-line* beneath the Equator is between 15,000 and 16,000 feet above the level of the sea; on the south side of the Himalayan ridge, it is about 15,500 feet, but on the north side it rises to 18,500 feet; and in the Swiss Alps it is about 8000 feet. Its position is very much affected, however, by local circumstances, such as the neighbourhood of a large expanse of land or of sea; hence the small quantity of land in the Southern hemisphere renders its climate generally so much colder than that of the Northern, that in Sandwich Land (which is Lat. 59° S., or in the same parallel as the north of Scotland) the whole country, from the summits of the mountains down to the very brink of the sea-cliffs, is covered many fathoms thick with everlasting snow; and in the island of Georgia (which is in Lat. 54° S., or in the same parallel as Yorkshire), the limit of perpetual snow descends to the level of the ocean, the partial melting in

summer only disclosing a few rocks, scantily covered with moss and tufts of grass. Yet the highest mountains of Scotland, which ascend to an elevation of above 4000 feet, and are four degrees more distant from the equator, do not attain the limit of perpetual snow; this is reached, however, by mountains in Norway, at no greater elevation.

106. If, then, Temperature exert such an influence on Vegetable life as has been stated, we ought to find on the sides of lofty mountains in tropical regions, the same progressive alterations in the characters of the Plants that cover them, as we encounter in journeying from the equatorial towards the polar regions. This is actually the case. The proportion of Cryptogamia to Flowering-plants, for example, is no more than *one-fifteenth* on the *plains* of the Equatorial region; whilst it is as much as *one-fifth* on the *mountains*. In ascending the Peak of Teneriffe, Humboldt observed as many as five distinct zones, which were respectively marked by the products which characterize different climates. Thus at the base, the vegetation is altogether tropical; the Date-Palm, Plantain, Sugar-Cane, Banyan, the succulent Euphorbia, the Dracæna, and other trees and plants of the torrid zone there flourish. A little higher grow the Olive, the Vine, and other fruit-trees of Southern Europe; there Wheat flourishes; and there the ground is covered with grassy herbage. Above this is the woody region, in which are found the Oak, Laurel, Arbutus, and other beautiful hardy evergreens. Next above is the region of Pines; characterized by a vast forest of trees resembling the Scotch Fir, intermixed with Juniper. This gives-place to a tract remarkable for the abundance of Broom; and at last the scenery is terminated by Scrofularia, Viola, a few Grasses, and Cryptogamic plants, which extend to the borders of the perpetual snow that caps the summit of the mountain.

107. The effects of Temperature on Vegetation are not only seen in its influence upon the Geographical distribution of Plants, that is, in the limitation of particular species to particular climates; for they are shown, perhaps even more remarkably, in the variation in the size of individuals of the same species, when that species possesses the power of adapting itself to widely-different conditions, which is the case with some. Thus the *Cerasus Virginiana*, which rears itself in the southern states of North America as a noble tree attaining one hundred feet in height, when growing in the sandy plains of the Saskatchawan does not exceed twenty feet, whilst at its northern limit, the Great Slave Lake, in Lat. 62°, it is reduced to a shrub of five feet. Another curious effect of heat is shown in its influence on the sexes of certain Monœcious flowers; thus Mr. Knight mentions that Cucumber and Melon plants will produce none but male or staminiferous flowers, if their vegetation be accelerated by heat; and all female or pistilline, if its progress be retarded by cold.

108. The injurious influence of excessive Heat can be, to a certain

extent, resisted by Plants, through the cooling process kept-up by the continual evaporation of moisture from their surface. But the power of maintaining this cooling process, entirely depends upon the supply of fluid with which the plant is furnished. If the supply be adequate to the demand, the effect of heat will be to stimulate all the vital operations of the plant, and to cause them to be performed with increased energy; though, as we have already seen, this energy may be such as to occasion a premature exhaustion in its powers, by the excessive luxuriance which it occasions. But if the supply of water be deficient, the plant is burnt-up by the continuance of heat in a dry atmosphere; and it either withers and dies, or its tissues become dense and contracted, without losing their vitality. Thus shrubs growing among the sandy deserts of the East have as stunted an appearance as those attempting to vegetate in the Arctic regions; their leaves being converted into prickles, and their leaf-buds prolonged into thorns instead of branches. The influence of excessive heat in destroying life can sometimes be traced through the direct physical changes which it occasions in the vegetable tissues. Thus it has been ascertained that grains of corn will vegetate, after exposure to water or vapour possessing a considerable degree of heat, provided such heat do not amount to 144° in the case of water, and 167° in that of vapour; for at these temperatures, the structure of the seed undergoes a disorganizing change, by the rupture of the vesicles of starch which form a large part of it, so that the loss of its power of germinating is therefore readily accounted-for. The highest temperature which the soil usually possesses in tropical climates, is about 126°, though Humboldt has once observed the thermometer rise to 140°. Seeds imbedded in such a soil, therefore, may not lose their vitality, although they will not germinate in such temperatures. The temperature most favourable to germination probably varies in different species, and is one of the conditions that produces their adaptation to different climates. Thus it appears that Corn will not germinate in water at a higher temperature than 95°, whilst Maize will germinate in water at 113°; and, as is well known, Maize will flourish in countries in which Corn cannot be grown.

109. We must not confound the power which plants possess of *vegetating*, or exhibiting *vital activity*, under widely-different degrees of temperature, with the power of retaining their *vitality* in a dormant condition, which many of them possess in a very remarkable degree. When the external temperature is much below the freezing-point, it is impossible that any vegetating processes can go-on; since the Plant does not possess the power of generating heat within itself. Now such a complete cessation of activity is quite compatible, in many instances, with the preservation of the organized structure in a condition perfectly unchanged, and, in consequence, with the continuance of its peculiar properties; so that these properties may

be again called into operation, when the temperature shall have risen. But in other cases, the plant may be *killed* by the intensity of the cold; that is, the return of warmth will not excite it to activity. We have occasion to notice, in every severe winter, the difference in this respect amongst the plants which are cultivated in our own climate; some of them being killed by a hard frost, the effects of which are resisted by others, even though their situation be more exposed. In general it will be found, that the cold acts most powerfully (as might be expected) upon plants which are not indigenous to our country, but which have been introduced and naturalized from some warmer regions. But it is worthy of note, amongst other peculiarities in the relation of Heat and Vegetation, that many plants are readily killed by a low temperature, which yet flourish well under a very moderate amount of warmth; so that they will grow in situations where the mean temperature of the year is low and the summers cool, provided the winters are not severe; whilst they cannot be preserved without special protection, in situations where the winters are colder, even though the summers should be much hotter, and the mean temperature of the whole year should be considerably higher. Thus there are shrubs flourishing in the Botanic Garden of Edinburgh, which cannot be safely left in the open air in the neighbourhood of London, and which would be most certainly killed by the winter-cold of central France.

110. It scarcely admits of doubt, that the destructive influence of a very low temperature upon the Vitality of Plants, is immediately exerted through its chemical and physical effects upon their fabric. Thus it will produce congelation of their fluids; and the expansion which takes-place in freezing will injure the walls of the containing cells,—distending, lacerating, or even bursting them. The same cause will probably occasion the expulsion of air from some parts which ought to contain it; and the introduction of it into other parts which ought to be filled with fluid. And a separation must take place, in the act of freezing, between the constituent parts of the vegetable juices; which will render them unfit for discharging their functions, when returning warmth would otherwise call them into activity. Hence we are enabled in some degree to account for the differences in the power of resisting cold, which the various species of Plants, and even the various parts of the same individual, are found to possess. For, other things being equal, the power of each plant, and of each part of a plant, to resist a low temperature, will be in the inverse ratio of the quantity of water contained in the tissue; thus, a succulent herbaceous plant suffers more than one with a hard woody stem and dense secretions; and young shoots are destroyed by a degree of cold, which does not affect old shoots and branches of the same shrub or tree. Again, the viscidity of the fluids of some plants is an obstacle to their congelation, and therefore enables them to resist cold; thus it is that the

resinous Pines are, of all trees, those which can endure the lowest temperature. The dimensions of the cells, too, of which the tissue is composed, appear to have an influence; the liability to freeze being diminished by a very minute subdivision of the fluids. And when the roots are implanted deep in the soil, where the temperature does not fall by many degrees so low as that of the surface, the fluidity of the sap may be maintained, in spite of an extremely cold state of the atmosphere. It is a fact of much interest, which has been recently substantiated by the researches of Prof. Tyndall, that the heat-conducting power of wood is far less in the direction from the surface to the centre of a stem, than in the direction of its length; so that whilst the coldness of the atmosphere thus exerts a *minimum* of influence upon the temperature of the interior of the trunk, the comparative warmth of the deeper soil has its *maximum* of effect.

111. It is in Cryptogamic plants, that the greatest power of sustaining Cold exists; as might be inferred from what has been already stated in regard to their geographical distribution. The little Fungus (*Torula Cerevisiæ*) which is one of the principal constituents of Yeast, does not lose its vitality by exposure to a temperature of 76° *below zero;* though it requires a somewhat elevated temperature for its active growth.—It would appear that *Seeds* are enabled to sustain a degree of cold, without the loss of their vitality, which would be fatal to growing plants of the same species; thus grains of corn, of various kinds, will germinate after being exposed for a quarter of an hour to a temperature equal to that of frozen mercury. It is not difficult to account for this, when the closeness of their texture, and the small quantity of fluid which it includes, are kept in view. The act of Germination, however, will only take place under a rather elevated temperature; and we find, in the Chemical changes which it involves, a provision for maintaining this, when the process has once commenced.

112. The influence of Heat upon the vital activity of Animals, is quite as strongly marked as we have seen it to be in the case of Plants; but the mode in which it is exerted, is in many instances very different. In those animals which are endowed with great and sustained energy of muscular movement, and in which, for the maintenance of that energy, the nutritive functions are kept in constant activity, we find that a provision exists for the development of heat from within, so as to keep the temperature of the body at a certain uniform standard, whatever may be the climate in which they live. Their energy and activity, are, in fact, so dependent upon the steady maintenance of a high temperature in their bodies, that, if this be not kept-up nearly to its regular standard, a diminution or even a complete cessation of vital activity takes-place, and even a total loss of vitality may result. In these *warm-blooded* animals, as they are termed, we do not so evidently

trace the effects of Heat, because they are constantly being exerted, and because *external* changes have but little influence upon them, unless these changes be of an extreme kind. But if those *internal* operations on which the maintenance of the temperature is dependent, are from any cause retarded or suspended, the effect is immediately visible. In the class of Birds, whose muscular energy, and whose general functional activity, are greater and more constant than those of any other animals, the temperature is pretty steadily maintained at from 108° to 112°; and we shall presently see that a depression of the heat of the body to about 80° is fatal. Among Mammalia, the temperature is usually maintained at from 98° to 102°; and it seems that in them, too, a depression of about thirty degrees is ordinarily fatal.

113. In the different tribes of Birds and Mammals, we find a very diversified power of generating heat; and on this depends their adaptation to various climates. Where the usual temperature of the atmosphere is but little below the normal standard of the body, a small amount of the internal calorifying power is required; and accordingly we find that animals which naturally inhabit the torrid zone, cannot be kept alive elsewhere, except, like the Plants of the same regions, by external heat. On the other hand, the animals of the colder-temperate and frigid climes are endowed with a much greater internal calorifying power; and their covering is adapted to keep-in the heat which they generate. Such animals (the Polar Bear for example) cannot be kept in health, in the summer of our own country, unless means be taken for their refrigeration. The constitution of Man seems to acquire, by habituation to a particular set of conditions through successive generations, an adaptation to differences of climate, of which that of few other animals is susceptible; and thus we find different races of human beings inhabiting countries, which are subject to the extremes of heat and cold. The Hindoo or the Negro, suddenly transported to Labrador or Siberia during the depth of winter, would probably sink in the course of a few days, from want of power to generate within his body an amount of heat sufficient to enable it to resist the depressing influence of the external cold; whilst on the other hand, the Esquimaux, suddenly conveyed to the hottest parts of India or Africa, would speedily become the subject of disease, which would probably terminate his life in a short time. It is in the inhabitant of temperate climates, who is naturally exposed during the seasonal changes of his year, to a wide range of external temperature, that we find the greatest power of sustaining the extremes of either cold or heat; and yet, even in such, the continued exposure to either extreme during a long series of years, will so much influence the heat-producing power, as to prevent the constitution from adapting itself readily to a change of conditions.

114. We see, then, that the variations observable between different races in this respect, are only exaggerations (so to speak) of the alternations which an individual may undergo in the course of a few years; and it is easy to understand how such an adaptation may take place to an increased extent in successive generations;—this being the regular law, not merely in regard to Man, but in regard to other animals placed under new conditions, to which they have a certain, but *limited*, power of adapting themselves. Thus we find that an European, who has lived for several years in the East or West Indies, suffers considerably from the cold, when he first returns to winter in his native country; his constitution having, for a time, lost some of its power of generating heat. After a few years' residence, however, this power is commonly recovered to its original extent, unless the age of the individual be too far advanced; but his children, if they have been not only born, but brought-up, in the hotter climate, experience much greater difficulty in adapting themselves to the colder one.

115. The conditions on which the power of maintaining the heat of the body, in despite of external cold, is dependent, will become the subject of inquiry hereafter (CHAP. X). It is sufficient here to state, that this power is the result of numerous Chemical changes going-on within the body; and especially of a process analogous to combustion, in which carbon and hydrogen, taken-in as food, are made to unite with oxygen derived from the atmosphere. It is dependent, therefore, as to its amount, upon the due supply of the combustible material on the one hand, and of atmospheric air on the other. If the former be not furnished either by the food, or by the fatty matter of the body (which acts as a kind of reserve store laid-up against the time of need), the heat cannot be maintained; and it is in part for want of power to digest and assimilate a sufficient amount of this kind of aliment, that animals of warm climates cannot maintain their temperature in colder regions. On the other hand, if the supply of oxygen be deficient, as it is when the respiration is impeded by diseased conditions of various kinds, there is a similar depression of temperature.

116. Now if, from either of these causes, the temperature of the body of a Bird or Mammal (except in the case of the *hybernating* species of the latter, to be presently noticed), be lowered to about 30° below its usual standard, not only is there a cessation of vital *activity*, but a total loss of vital *properties;* in other words, the *death* of the animal is a necessary result. This occurrence is preceded by a gradually-increasing torpidity; which shows the depressing influence of the cooling process upon the functions in general. The temperature of the superficial parts of the body is, of course, affected earliest; the circulation is at first retarded, causing lividity of the skin; but, as the temperature becomes lower, the blood is almost entirely expelled from the surface by the

contraction of the vessels, and paleness succeeds. At the same time, there is a gradually-increasing torpor of the nervous and muscular systems, which first manifests itself in an indisposition to exertion of any kind, and then in an almost irresistible tendency to sleep. At the same time, the respiratory movements become slower, from the want of the stimulus that should be given by the warm current of blood to the Medulla Oblongata, which is the centre of those movements; and the loss of heat goes-on, therefore, with increased rapidity, until the temperature of the whole body is so depressed, that its vitality is altogether destroyed.

117. But when there is a deficiency of the proper *animal* heat, the vital activity of the system may be maintained by caloric supplied by external sources. This fact is of high scientific value, as giving the most complete demonstration of the *immediate* dependence of the vital functions of warm-blooded animals upon a sustained temperature; and its practical importance can scarcely be over-rated. It rests chiefly upon the experiments of Chossat, who had in view to determine the circumstances attending death by Inanition or starvation. He found that, when Pigeons were entirely deprived of food and water, their average temperature underwent a tolerably-regular diminution from day to day; so that, after several days (the exact number varying with their previous condition), it was about $4\frac{1}{2}^{\circ}$ lower than at first. Up to this time, it seems that the store of fat laid-up in the body supplies the requisite material for the combustive process; so that no very injurious depression of temperature occurs. But, as soon as this is exhausted, the temperature falls rapidly from hour to hour; and by the time that the total depression reaches $29\frac{1}{2}^{\circ}$ or 30°, death supervenes. Yet it was found by M. Chossat, that when animals thus reduced by starvation, whose death seemed impending (death actually taking place in many instances whilst the preliminary processes of weighing, the application of the thermometer, &c., were being performed), were subjected to artificial heat, they were almost uniformly restored, from a state of insensibility and want of muscular power, to a condition of comparative activity. Their temperature rose, their muscular power returned, they took food when it was presented to them, and their secretions were renewed; and if this artificial assistance was sufficiently prolonged, and they were supplied with food, they recovered. If the heat was withdrawn, however, before the time when digested food was ready, in sufficient amount, to supply the combustive process, they still sank for want of it.

118. Various important practical hints may be derived from the consideration of these facts. There can be no doubt that in many diseases of exhaustion, the want of power to sustain the requisite temperature is the *immediate* cause of death: the whole combustible material of the body having been exhausted, and the

digestive apparatus not being able to supply what is required. Now where this is the case, life may be prolonged and recovery favoured by the judicious sustentation of the temperature of the body. This may be effected either by internal or by external means. Of the internal, the most efficient is undoubtedly the administration of Alcoholic fluids; which, for reasons hereafter to be given (§ 495), will be absorbed into the circulating system, when no other alimentary substance can be taken-in; and which, moreover, exert a favourable influence, by their specific stimulating effect, upon the nervous system. It is a matter of familiar experience, that, in such conditions of the body, the quantity of alcohol which may be administered with positive and evident benefit, is such as would in ordinary circumstances be productive of the most injurious results; and this is fully accounted-for by the reflection, that it is *burnt-off* as fast as it is taken-in. But a most important adjunct in all such cases,—and in many instances a substitute for alcohol when the latter would be inadmissible,—will be found in the application of *external* heat; and especially in the subjection of the entire surface to its influence, by means of the hot-air bath. This is a valuable portion of the treatment, in the recovering of persons who have been reduced to insensibility by suffocation of any kind; and especially in cases of drowning, since the heat of the body is rapidly withdrawn by the conducting power of the water. Indeed it may be stated as a general rule, that, where the temperature of the body is lowered from any cause, *external heat* may be advantageously applied; and much evidence has been produced to show, that the reparative processes by which extensive wounds are healed, go-on more favourably under the contact of warm dry air, than with any other application.

119. On the other hand, where the object is to keep-down a tendency to a too-violent action, the local application of moderate *cold* is found to be of the greatest value; all surgeons of eminence being now agreed upon the efficacy of *water-dressing* in restraining the inflammatory process, especially in cases of wounds of the joints, in which this action is most to be apprehended. The *general* application of cold to the surface, by means of continued exposure to cool air, or by a short immersion in cold water, is frequently in the highest degree beneficial, by imparting *tone* to the system, *i.e.*, by producing a firmer condition in the solids which were previously relaxed, and more especially by calling into action the *tonicity* of the walls of the blood-vessels, which imparts to them an increased resistance, and thus favours the regular and vigorous circulation of blood, upon principles which will be hereafter stated (§ 609). But so far from producing any permanent depression in the temperature of the body, this measure has a tendency to elevate it, by the increased vigour it produces in the circulation; hence the glow which is experienced after the use of the cold bath. If this effect

be *not* produced, and a chilling of the body, instead of an invigorating warmth, be the result of the use of cold, it is evident that this cannot be beneficial. The injurious results of the too-prolonged application of even a moderate degree of cold, are seen in the depression of temperature, without a corresponding reaction, which is the consequence of an immersion in water of 50° or 55° prolonged for several hours; and still more in that chilling of the whole surface, frequently productive of the most serious consequences, which arises from the evaporation of fluid from garments that have been moistened, either by perspiration from within, or by the fall of rain or dew upon their exterior. There is no doubt that the obstruction to the continuance of the perspiration, presented by a covering already saturated with moisture, is one cause of the injurious results that so commonly follow such an occurrence; but there is as little doubt that the chilling influence of the external evaporation has a large share in producing them. For experience shows that, if the evaporation be prevented by an impenetrable covering, the contact of a garment thoroughly saturated with moisture is not productive of the same injurious consequences.

120. The practical importance of the due comprehension of the principles upon which Heat and Cold should be employed in the treatment of disease and the preservation of health, has required this digression. We now proceed to consider the influence of temperature upon a certain group of warm-blooded animals; which offers a remarkable peculiarity in this respect,—their power of generating heat being for a time greatly diminished or almost completely suspended; the temperature of their bodies following that of the air around, so that it may be brought-down nearly to the freezing-point; their general vital actions being carried-on with such feebleness as to be scarcely perceptible; and yet the vital properties of the tissues being retained, so that, when the temperature of the body is again raised, the usual activity returns. This state, which is called *hybernation*, appears to be as natural to certain animals, as sleep is to all; and it corresponds with sleep in its tendency to periodical return.

121. No account can be given of the causes to which Hybernation is due; but the condition of the animals presenting it, offers several points of much interest. There are some, as the *Lagomys*, in which it appears to differ but little from deep ordinary sleep; they retire into situations which favour the retention of their warmth; and they occasionally wake-up, and apply themselves to some of the store of food, which they have provided in the autumn. In other cases, a great accumulation of fat takes-place within the body in autumn, favoured by the oily nature of the seeds, nuts, &c., on which the animals then feed; and this serves the purpose of maintaining the temperature for a sufficient length of time, not indeed at the usual standard, but at one not far below it. The state of

torpor in these animals is more profound than that of deep sleep, but it is not such as to prevent them from being easily aroused; and their respiratory movements, though diminished in frequency, are still performed without interruption. But in the *Marmot*, and in animals which, like it, hybernate completely, the temperature of the body (owing to the want of internal power to generate heat) and the general vital activity are proportionably depressed; the respiratory movements fall from 500 to 14 per hour, and are performed without any considerable enlargement of the chest; the pulse sinks from 150 to 15 beats per minute; the state of torpidity is so profound, that the animal is with difficulty aroused from it; and the heat of the body is almost entirely dependent upon the temperature of the surrounding air, not being usually more than a degree or two above it. When the thermometer in the air is somewhat below the freezing-point, that placed within the body falls to about 35°; and at this point it may remain for some time, without any apparent injury to the animal, which revives when subjected to a higher temperature. When, however, the body is exposed to a more intense degree of cold, the animal functions undergo a temporary renewal; for the cold seems to act like any other stimulus in arousing them. The respiratory movements and the circulation increase in activity, so as to generate an increased amount of heat; but this amount is insufficient to keep-up the temperature of the body, which is at last depressed to a degree inconsistent with the maintenance of life; and not only the suspension of activity, but the total loss of vital properties, is the result.

122. Now the condition of a hybernating Mammal closely resembles that of a cold-blooded animal, in regard to the dependence of its bodily temperature upon external conditions. There is this important difference, however:—that the reduction of the temperature of the former to 60° or 50° is incompatible with the continuance of their activity, which is only exhibited when the temperature rises to nearly the usual Mammalian standard;—whilst a permanently low or moderate temperature is natural to the bodies of most cold-blooded animals, whose functions could not be well carried-on under a higher temperature. Thus all the muscles of a Frog are thrown into a state of permanent and rigid contraction, by the immersion of its body in water no warmer than the blood which naturally bathes those of the Bird; and we find, accordingly, that cold-blooded animals which cannot sustain a high temperature, are provided with a *frigorifying* rather than with a *calorifying* apparatus. Although we are accustomed to rank all animals, save Birds and Mammals, under the general term *cold-blooded*, yet there exist among them considerable diversities as to the power of generating heat within themselves, and of thus rendering themselves independent of external variations. Thus among Reptiles, it appears that there are some which can sustain a temperature several

degrees above that of the atmosphere, especially when the latter is sinking; and among Fishes, it is certain that there are species,—the *Thunny* and *Bonito* for example,—which are almost entitled to the name of warm-blooded animals, their temperature being kept-up to nearly 100°, when that of the sea is about 80°. It is uncertain, however, to what extent it would be depressed, by a lowering of that of the surrounding medium. The greatest power of developing heat in cold-blooded animals appears to exist, when their bodies are reduced nearly to the freezing-point; and when that of the surrounding air or water is much below it. Thus Frogs have been found alive in the midst of ice whose temperature was as low as 9°, the heat of their own bodies being 33°; and it has been observed that even Animalcules contained in water that is being frozen, are not at once destroyed, but that each lives for a time in a small uncongealed space, where the fluid seems to be kept from solidifying by the caloric liberated from the Animalcule.

123. The peculiar condition of the class of Insects, in regard to its heat-producing power, exhibits in a very striking manner the connection between an elevated temperature and vital activity. In the *Larva* state of Insects, the temperature of the animal follows closely that of the surrounding air, as in the cold-blooded classes generally; but it is usually from $\frac{1}{2}$° to 4° above it. In the *Pupa* condition, which is one of absolute rest in most insects that undergo a complete metamorphosis, the temperature scarcely rises above that of the surrounding medium; except at nearly the close of the period, when the creature is about to burst its envelopes and to come-forth as the perfect Insect. The temperature which different Insects possess in their *Imago* state, varies in part according to the species, and in part with the condition of the individual in regard to rest or activity; but the same principle is evidently operating in both cases, since the variation existing amongst different species, in regard to their heat-producing power, is closely connected with the amount of activity natural to them. The highest amount is to be found in the industrious Hive-Bee and its allies, and in the elegant and sportive Butterflies, which are almost constantly on the wing in search of food; next to these come the Beetles of active flight; and lastly those which seldom or never raise themselves upon the wing, but pursue their labours on the ground. The temperature of individual Bees has been found to be about 4° above that of the atmosphere when they are in a state of repose; but it rises to 10° or 15° when they are excited to activity. When they are aggregated-together in clusters, however, the temperature which they possess is often as much as 40° above that of the atmosphere. When reduced to torpidity by cold, they still generate heat enough to keep them from being frozen, unless the cold be very severe; and they may be aroused by moderate excitement to a state of activity, in which the temperature rises to a very considerable elevation. Now although

the increased production of heat is in these cases, as in hybernating Mammals similarly aroused, the *consequence* of the increased activity, there can be no question that it is a condition necessary to the *continuance* of that activity; since we find that, if the temperature of the body be again reduced by external cold, such activity cannot be long maintained.

124. Whilst the foregoing facts exhibit the connection between an elevated temperature and the highest activity of the muscular and nervous systems, in cold-blooded animals, there is abundant evidence of the same kind in regard to the influence of Heat upon the processes of nutrition and development. Thus the time of emersion of Insect-larvæ from their eggs,—or in other words, the rate at which the antecedent formative processes go-on,—is entirely dependent upon the temperature. In the case of the Bird, we find that if the temperature be not sufficient to develope the egg, chemical changes soon take-place, which involve the loss of its vitality; or if the temperature be reduced so low as to prevent the occurrence of those changes, the loss of heat is in itself destructive of life. But this is not the case in regard to the eggs of cold-blooded animals in general; for, like the beings they are destined to evolve, they may be reduced to a state of complete inactivity by a depression of the external temperature; whilst a slight elevation of this renews their vital operations, at a rate corresponding to the warmth supplied. Hence the production of larvæ from the eggs of Insects may be accelerated or retarded at pleasure; and this is, in fact, practised in the rearing of Silk-worms, in order to adapt the time of their emersion from the egg to that of the evolution of the leaves on which they feed. The same may be said in regard to the eggs of other cold-blooded animals; those, for example, of the minute Entomostraceous Crustacea (Water-Fleas, &c.) which people our ditches and ponds. In many of these, the race is continued solely by the eggs, which remain dormant through the winter; all the parents being destroyed by the cold. The common *Daphnia pulex* produces two kinds of eggs; from one, the young are very speedily hatched; but the others, which are produced in the autumn and are enveloped in a peculiar covering, do not give-birth to the contained young until the succeeding spring. They may be at any time hatched, however, by artificial warmth.

125. We sometimes find special provisions, for imparting to the eggs a temperature beyond that which is natural to the bodies of the parents; thus in Serpents, the temperature of the posterior part of the body rises considerably, when the eggs are lying in the oviduct, preparatory to being discharged,—evidencing a special heat-producing power in the surrounding parts at this period, which is obviously for the purpose of aiding the maturity of the eggs. The Viper, whose eggs are frequently hatched in the maternal oviduct, so that the young are brought-forth alive, is occasionally seen

basking in the sun, in such a position as to receive its strongest heat on the parts that cover the oviduct. Certain birds have recourse to substitutes for the usual method of incubation. The *Tallegalla* of New Holland is directed by its remarkable instinct, not to sit upon its eggs, but to bring them to maturity by depositing them in a sort of hot-bed, which it constructs of decaying vegetable matter. The Ostrich is believed to sit upon its eggs, when the temperature falls below a certain standard, but to leave them to the influence of the solar heat when this is sufficient to bring them to maturity; and this statement derives confirmation from a similar fact observed in a Fly-catcher, which built in a hothouse during several successive years,—the bird quitting its eggs when the temperature was high, and resuming its place when it fell. In all these cases, as in many more which might be enumerated, we observe the influence of an elevated temperature upon the processes of development; and we find a provision made by Nature, either in the physical or in the mental constitution of animals, for affording that influence. The development of heat around the oviduct of the Serpent is a process over which the individual has no control, being entirely dependent upon certain Organic changes; whilst the imparting of warmth to its eggs by the Bird, either from its own body or through artificial means, is committed to the guidance of its Instinct,—which same instinct leads it to suspend the process when it is not necessary.

126. Phenomena of an equally interesting and instructive character may be observed in the history of the Pupa-state of Insects; which, in those that undergo a complete metamorphosis, may be almost characterized as a re-entrance into the egg. In fact we shall obtain the most correct idea of the nature of that metamorphosis, by considering the Larva as an embryo, which comes-forth from the egg in a very early and undeveloped condition, for the sake of obtaining materials for its continued development, which the egg does not supply in sufficient amount. When these have been digested and stored-up in the body, the animal becomes completely inactive, so far as regards its external manifestations of life; and it forms some kind of envelope for its protection, which may not be unaptly compared to the shell or horny covering of the egg. Within this are gradually developed the wings, legs, and other parts which are peculiar to the perfect Insect; whilst even those organs which it possesses in common with the Larva, are for the most part completely altered in character. When this process of development is completed, the Insect emerges from its Pupa case, just as the Bird comes-forth from the egg; then only does its Insect life begin, its previous condition having been that of a Worm; and the alteration of its character is just as evident in its instinctive propensities, as it is in its locomotive and sensorial powers.

127. Now this process of development is remarkably influenced by external temperature; being accelerated by genial warmth, and retarded by cold. There are many Larvæ, which naturally pass into the Pupa state during the autumn, remain in it during the entire winter, and emerge as perfect Insects with the return of spring. It was found by Reaumur, that Pupæ which would not naturally have been disclosed until May, might be caused to undergo their metamorphosis during the depth of winter, by the influence of artificial heat; whilst, on the other hand, their change might be delayed a whole year beyond its usual time, by the prolonged influence of a cold atmosphere. In order to hasten the development of the pupæ of the Social Bees, a very curious provision is made. There is a certain set to which the name of Nurse-bees has been given, whose duty it is to cluster over the cells in which the 'nymphs' or Pupæ are lying, and to communicate to them the heat which is developed by the energetic movements of their own bodies, and especially by respiratory actions of extreme rapidity. The 'nurse-bees' begin to crowd upon the cells of the nymphs, about ten or twelve hours before these last come-forth as perfect Bees. The incubation (for so it may be called) is very assiduously persevered-in during this period by the 'nurse-bees;' when one quits the cell, another takes its place; and the rapidity of the respiratory movements increases, until they rise to 130 or 140 per minute, so as to generate the greatest amount of heat just before the young bees are liberated from the combs. In one instance, the thermometer introduced among seven 'nurse-bees' stood at 92½°; the temperature of the external air being 70°. We observe in this curious propensity a manifest provision for accelerating the development of the perfect Insect, which requires (as already pointed-out) a higher temperature than the larva, in virtue of its greater activity. The 'nurse-bees' do not station themselves over the cells which are occupied by the larvæ; nor do they incubate the nymph-cells with any degree of constancy and regularity, until the process of development is approaching its highest point.

128. The influence of variations in the Heat of the body upon its vital activity, is further manifested by the very remarkable experiments of Dr. Edwards; who has shown that Cold-blooded animals *live much faster* (so to speak) at *high* temperatures, than at low; so that they die much sooner, when deprived of other vital stimuli. —Thus when *Frogs* were confined in a limited quantity of water, and were not permitted to come to the surface to breathe, it was found that the duration of their lives was inversely proportional to the degree of heat of the fluid. Thus when it was cooled-down to the freezing-point, the duration of the life of frogs immersed in it was from 367 to 498 minutes; at the temperature of 50°, this was from 350 to 375 minutes; at 72°, it was from 90 to 35 minutes; at 90°, from 12 to 32 minutes; and at 108°, death was almost

instantaneous. The prolongation of life at the lower temperatures is not due to torpidity, for the animals perform the functions of voluntary motion, and enjoy the use of their senses; but it is occasioned by their diminished activity, which occasions a less demand for air. On the other hand, the elevation of temperature increases the demand for air, and causes speedier death when it is withheld; by increasing the general agility. The natural habits of these animals are in correspondence with these facts. During the winter, the influence of a sufficient amount of aerated water upon their exterior serves to maintain the required amount of respiration through the skin, so that they are not obliged to come to the surface to take-in air by the mouth. As the season advances, however, their activity increases, a larger amount of respiration is required, and the animals are obliged to come frequently to the surface to breathe. During summer, the yet higher temperature calls-forth an increased energy and activity in all the vital functions; the respiration must be proportionably increased; the action of the air upon the cutaneous surface, as well as upon the lungs, is required; and if the animals be prevented from quitting the water to obtain this, they die as soon as the warmth of the season becomes considerable.—The result of experiments on *Fishes*, in regard to the deprivation or limited supply of the air contained in the water in which they are immersed, is exactly similar; the duration of life being inversely as the temperature. And precisely the same has been ascertained with respect to hybernating Mammals; which, as already remarked, are for a time reduced, in all such conditions, to the level of cold-blooded animals.

129. The energy of the *reparative* actions of Animals is much influenced by temperature, as might be inferred from what has been just said of their nutritive and developmental operations. Thus the rate at which regeneration of lost parts, as also that of the ordinary process of budding, takes-place in the common *Hydra* (fresh-water polype), is in close accordance with the temperature in which it lives; and in like manner, the healing of wounds in Frogs takes place more rapidly in summer than in winter. In many of the higher animals, indeed, it appears that the complete *regeneration* of parts requires a higher temperature, than is necessary to sustain the ordinary vital activity. Thus it has been found that the common *Triton* (water-newt) can reproduce a limb that has been cut-off, if it be kept at a temperature of from 58° to 75°; but cannot do so if a less amount of heat be afforded to it. And in like manner, the Snail can regenerate its head, if it be kept in a warm atmosphere, but not at a low temperature.—Now it has been justly remarked by Mr. Paget, that the process of *development* seems to require a higher amount of Vital force than simple *growth*; and we see that the relation already pointed-out between Heat and Vital force, here holds-good in such a marked

degree, as to afford a strong confirmation of the idea of their mutual relationship.

130. It is quite conformable to the same principle, that we should find Cold-blooded animals able to sustain the deprivation of food during a much longer period, at low temperatures, than at high The case is precisely the reverse, however, in regard to most Warm-blooded animals; since in *them* a due supply of food is a condition absolutely necessary (as we have already seen) for the maintenance of that amount of bodily heat, whose loss is fatal to them; and exposure to a low temperature will of course more speedily bring-about that crisis. Hence it is that Cold and Starvation combined are so destructive to life. But in this respect also, the hybernating Mammals correspond with the cold-blooded classes; their power of abstinence being inversely as the temperature of their bodies.

131. We have seen that the animals termed *cold-blooded* are greatly influenced as to the temperature of their bodies, by the temperature of the surrounding medium; although many of them are endowed with the power of keeping themselves a certain number of degrees above it. Now the consequence of this is, that all of them which are subject to any considerable and prolonged amount of cold, pass into a state of more or less complete inactivity during its continuance; which state bears a close correspondence with the hybernation of certain Mammalia. Among the Reptiles of cold and temperate countries, this torpid state uniformly occupies a considerable part of the year; as it does also with Insects, terrestrial Mollusks, and other Invertebrated animals, which are subject to the influence of the cold. On the other hand, Fishes, Crustacea, and other marine animals, do not usually appear to pass into a state of torpidity; the temperature of the medium they inhabit never undergoing nearly so great a degree of depression, as does that of the atmosphere.

132. The amount of change necessary to produce this effect, or on the other hand to call the animals from a state of torpidity to one of active energy, differs for different species; and there is probably a considerable difference even among individuals of the same species, according to the temperature under which they habitually live. Thus one animal may remain torpid under a degree of warmth which will be sufficient to arouse another of the same kind, accustomed to a somewhat colder climate; because the stimulus is *relatively* greater to the latter. For example, it was observed by Mr. Darwin, that at Bahia Blanca in South America, the first appearance of activity in animal and vegetable life, a few days before the vernal equinox, presented itself under a mean temperature of 58°, the range of the thermometer in the middle of the day being between 60° and 70°. The plains were ornamented by the flowers of a pink wood-sorrel, wild peas, evening primroses, and geraniums; the birds began to lay their eggs; numerous beetles

were crawling about; and lizards, the constant inhabitants of a sandy soil, were darting-about in every direction. Yet, a few days previously, it seemed as if nature had scarcely granted a living creature to this dry and arid country; and it was only by digging in the ground that their existence had been discovered,—several insects, large spiders, and lizards, having been found in a half-torpid state. Now at Monte Video, four degrees nearer the Equator, the mean temperature had been above 58° for some time previously, and the thermometer rose occasionally during the middle of the day to 69° or 70°; yet with this elevated temperature, nearly equivalent to the full summer heat of our own country, almost every beetle, several genera of spiders, snails, and land-shells, toads and lizards, were still lying torpid beneath stones.—From this example we see how nicely the effective degree of stimulus is adapted to the general climate of the place, and how little relation it has to absolute temperature.

133. We may learn much from the Geographical distribution of the different species of cold-blooded animals, in regard to the influence of temperature on Animal life. No general inferences of this kind can be founded upon the distribution of warm-blooded animals; since their own heat-evolving powers make them in great degree independent of external warmth. It is probably from the distribution of the marine tribes, whose extension is less influenced by local peculiarities, that the most satisfactory deductions are to be drawn. In regard to the class of *Crustacea*, which is the one that has been most fully investigated in this respect, the following principles have been pointed-out by M. Milne-Edwards; and they are probably more or less applicable to most others:—

I. Diversities of form and organization manifest themselves more, in proportion as we pass from the Polar Seas towards the Equator.

II. The differences of form and organization are not only more numerous and more characteristic in the warm than in the cold regions of the globe; they are also more important.

III. Not only are those Crustacea which are most elevated in the scale, deficient in the Polar regions; but their relative number increases rapidly, as we pass from the Pole towards the Equator.

IV. When we compare together the Crustacea of different parts of the world, we observe that the average size of these animals is considerably greater in tropical regions, than in the temperate or frigid climes.

V. It is where the species are most numerous and varied, and where they attain the greatest size, in other words, where the temperature is most elevated,—that the peculiarities of structure which characterize the several groups, are most strongly manifested.

VI. Lastly, there is a remarkable coincidence between the temperature of different regions, and the prevalence of certain forms of Crustacea.

134. Now although, as appears from the foregoing general statements, the number of *species* of Crustacea inhabiting the colder seas bears a very small proportion to that which is found within the tropics, and although the species formed to inhabit cold climates are so far inferior both as to size and as to perfection of development, yet it does not follow that the same proportion exists in regard to the relative amount of Crustacean life in the two regions; for this depends upon the multiplication of *individuals*. In fact it may be questioned whether there is any inferiority in this respect; so abundant are some of the smaller species in the Arctic and Antarctic, as well as in the Temperate seas. Thus we see that a low range of temperature is as well adapted to sustain *their* life, as a higher range is to call-forth those larger and more fully-developed forms, which abound in the tropical ocean. There is an obvious reason why the *seas* of the frigid zones should be much more abundantly peopled than the *land;* the mean temperature of the former being much higher than that of the latter. And it would almost seem as if Nature had intended to compensate for the dreariness and desolation of the one, by the profuseness of life which she has fitted the other to support.

135. The influence of Temperature in producing a variation in the size of individual Animals of any one species, is not so strongly marked as it is in the case of Plants; for this reason, perhaps, that an amount of continued depression or elevation, which might be sustained by a Plant, but which would exert a modifying influence upon its growth, would be fatal to an Animal formed to exist in the same climate. Instances are not wanting, however, in which such a modifying influence is evident; and these, as might be anticipated, are to be met-with chiefly among the cold-blooded tribes. Thus the *Bulimus rosaceus*, a terrestrial Mollusk, is found on the mountains of Chili of a size so much less than that which it attains on the coast, as to have been described as a distinct species. And the *Littorina petræa* found on the *south* side of Plymouth Breakwater, acquires, from its superior exposure to light and heat (though perhaps also from the greater supply of nutriment which it obtains), twice the size common to individuals living on the north side within the harbour.—The following circumstance shows the favourable influence of an elevated temperature, in producing an unusual prolificness in fish; which must be connected with general vital activity. Three pairs of Gold-fish were placed, some years since, in one of the engine-dams or ponds common in the manufacturing districts, into which the water from the engine is conveyed for the purpose of being cooled: the average temperature of such dams is about 80°. At the end of three years, the progeny of these Fish, which were accidentally poisoned by verdigris mixed with the refuse tallow from the engine, were taken out by wheelbarrows-full. It is not improbable that the unusual supply of aliment, furnished by the refuse

grease that floats upon these ponds (which would impede the cooling of the water, if it were not consumed by the Fish), contributed with the high temperature to this unusual fecundity.

136. Although a very low temperature is positively inconsistent with the continuance of vital *activity*, in Animals as in Plants, yet we find that even very severe cold is not necessarily destructive of the vital *properties* of organized tissues; so that, on a restoration of the proper amount of heat, their functions may continue as before. Of this we have already noticed an example, in the case of frost-bitten limbs; but the fact is much more remarkable, when considered in reference to the whole body of an animal, and to the complete suspension of all its functions. Yet it is unquestionably true, not only of the lowest and simplest members of the Animal kingdom, but also of Fishes and Reptiles. In one of Captain Ross's Arctic Voyages, several Caterpillars of the *Laria Rossii* having been exposed to a temperature of 40° *below zero*, froze so completely, that, when thrown into a tumbler, they chinked like lumps of ice. When thawed, they resumed their movements, took food, and underwent their transformation into the Chrysalis state. One of them, which had been frozen and thawed four times, subsequently became a Moth. The eggs of the Slug have been exposed to a similar degree of cold, without the loss of their fertility. It is not uncommon to meet, in the ice of rivers and lakes, with Fishes which have been completely frozen, so as to become quite brittle, and which yet revive when thawed: marine fish, however, appear less capable of sustaining this change, to which they are of course far less likely to be subjected, than are the inhabitants of small collections of water. The same thing has been observed in regard to Frogs, Newts, &c.; and the experiment of freezing and subsequently thawing them, has been frequently put in practice. Spallanzani kept Frogs and Snakes in an ice-house for three years; at the end of which period they revived on being subjected to warmth.

137. It does not appear, however, that the like capability exists in the case of any warm-blooded animals; since if a *total* suspension* of vital activity take place in the body of a Bird or Mammal for any length of time, in consequence of the prolonged application of severe cold, recovery is found to be impossible. The power which exists in these animals, however, of generating a large amount of heat within their bodies, acts as a compensation for the want of the faculty possessed by the cold-blooded tribes; since they can resist, for a great length of time (if in their healthy or normal condition), the depressing influence of a temperature sufficiently low to produce a complete suspension in the activity of the latter.

* In the case of hybernating Mammals, the suspension is not total; and if it be rendered such, the same result follows as in other instances.

138. It only remains to say a few words regarding the degree of *heat* which certain Animals can sustain without prejudice, and which even appears to be congenial to them. Among the higher classes, this range *seems* to be capable of great extension. Thus many instances are on record, of a heat of from 250° to 280° being endured, in dry air, for a considerable length of time, without much inconvenience; and persons who have become habituated to this kind of exposure, can (with proper precautions) sustain a temperature of from 350° to 500°. In all such cases, however, the real heat of the body undergoes very little elevation; for, by means of the copious evaporation from its surface, the external heat is prevented from acting upon it. But if this evaporation be prevented, either by an insufficiency in the supply of fluid from within, or by the saturation of the surrounding air with moisture, the temperature of the body begins to rise; and it is then found that it cannot undergo an elevation of more than a few degrees, without fatal consequences. Thus in several experiments which have been tried on different species of warm-blooded animals, for the purpose of ascertaining the highest temperature to which the body could be raised without the destruction of life, it was found that as soon as the heat of the body had been increased, by continued immersion in a limited quantity of hot air (which would soon become charged with moisture), to 9°—13° above the natural standard, the animals died. In general, Mammals die, when the temperature of their bodies is raised to about 111°, the heat which is natural to the bodies of Birds. The latter also are killed by an equal elevation of their bodily heat above its natural standard.

139. Hence we see that the actual range of temperature, within which vital activity can be maintained in all such warm-blooded animals as do not hybernate, is extremely limited; a temporary elevation of the heat of the body to 13° above its natural standard, or a depression to 30° below, being positively inconsistent, not merely with the continuance of its vital operations, but also with the preservation of its vital properties: and a continued departure from that standard, to the extent of only a very few degrees above or below it, being very injurious. The provisions with which these animals are endowed, for generating *heat* in their interior, so as to supply the external deficiency, and for generating *cold* (so to speak), when the external temperature is too high, are therefore in no respect superfluous: but are positively necessary for the maintenance of the life of such animals, in any climate, save one whose *mean* should be conformable to their standard, and whose *extremes* should never vary more than a very few degrees above or below it. Such a climate does not exist on the surface of the earth.

140. The range of *external* temperature, within which cold-blooded animals can sustain their activity, is much more limited, as well in regard to its highest as to its lowest point; notwithstanding

that the range of *bodily* heat, which is consistent with the maintenance of their life, is so much greater. In those which, like the Frog, have a soft moist skin, which permits a copious evaporation from the surface, a considerable amount of heat may be resisted, provided the air be dry, and the supply of fluid from within be maintained.* But immersion in water of the temperature of 108°, is almost immediately fatal. In many other cold-blooded animals, elevation of the temperature induces a state of torpidity, analogous to that which is produced by its depression. Thus the *Helix pomatia* (edible snail) has been found to become torpid and motionless in water at 112°, but to recover its energy when placed in a colder situation. It would seem to be partly from this cause, but partly also from the deprivation of moisture, that the *hottest* part of the tropical year brings-about a cessation of activity in many tribes of cold-blooded animals, as complete as that which takes-place during the *winter* of temperate climates.

141. The highest limit of temperature compatible with the life of Fishes has not been certainly ascertained: and it appears probable that there are considerable variations in this respect amongst different species. Thus it is certain that there are some which are killed by immersion in water at 104°; whilst it is also certain that others can not only exist, but can find a congenial habitation in water of 113°, or even of 120°; and examples of the existence of Fishes in thermal springs of a much higher temperature than this, have been put on record. Various fresh-water Mollusks have been found in thermal springs, the heat of which is from 100° to 145°. Rotifers and other Animalcules have been met-with in water at 112°. Larvæ of Tipulæ have been found in hot springs of 205°; and small black Beetles, which died when placed in cold water, in the hot sulphur baths of Albano. Entozoa inhabiting the bodies of Mammalia and of Birds must of course be adapted to a constant temperature of from 98° to 110°; and they become torpid when exposed to a cool atmosphere. These lowly-organized animals seem more capable of resisting the effects of extreme heat, than any others;—at least if we are to credit the statement, that the Entozoa inhabiting the intestines of the Carp have been found alive, when the Fish was brought to table after being boiled.—In all such cases, it is to be remembered that the heat of the animal body must correspond with that of the fluid in which it is immersed; and we have here, therefore, evident proof of the compatibility of vital activity, in certain cases, with a very elevated temperature.

* The Frog has a remarkable provision for this purpose; in a bladder which is *structurally* analogous to our Urinary bladder, but which has for its chief function to contain a store of fluid for the exhaling process. It has been noticed that, when this store has been exhausted by continued exposure of the animal to a warm dry atmosphere, the bladder becomes full again, when the animal is placed in a moist situation, even though it should take-in no liquid by its mouth.

Additional and more exact observations, however, are much wanting on this subject.

3. *Of Electricity, as a Condition of Vital Activity.*

142. Much less is certainly known with respect to the ordinary influence of this agent, than in regard to either of the two preceding; and yet there can be little doubt, from the effects we observe when Electricity is powerfully applied, as well as from our knowledge of its connexion with all Chemical phenomena, that it is in constant though imperceptible operation. Electricity differs from both Light and Heat in this respect;—that no manifestation of it takes place so long as it is uniformly diffused, or is in a state of *equilibrium;* but in proportion as this equilibrium is disturbed, by a change in the electric condition of one body, which is prevented, by its partial or complete insulation, from communicating itself to others, in that proportion is a *force* produced, which exerts itself in various ways according to its degree. The *mechanical* effects of a powerful charge, when passed through a substance that is a bad conductor of Electricity, are well known; on the other hand, the *chemical* effects of even the feeblest current are equally obvious. The agency of Electricity in producing Chemical change is the more powerful, in proportion as there is already a predisposition to that change; thus, the largest collection of oxygen and hydrogen gases, or of hydrogen and chlorine, mingled together, may be caused to unite by the minutest electric spark, which brings into the condition required for their active exercise, the mutual affinities that were previously dormant. Hence it cannot but be inferred, that its agency in the Chemical phenomena of living bodies must be of an important character; but this may probably be exerted rather in the way of aiding decomposition, than in producing new combinations, to which (as we have seen) Light appears to be the most effectual stimulus. Thus it has been shown that pieces of meat, that have been electrified for some hours, pass much more rapidly into decomposition, than similar pieces placed under the same circumstances, but not electrified. And in like manner, the bodies of animals that have been killed by electric shocks, lose their vital endowments and pass into the putrescent state, much more readily than those of similar animals killed by an injury to the brain. It is well known, moreover, that in thundery weather, in which the electric state of the atmosphere is much disturbed, various fluids containing albuminous compounds, such as milk, broth, &c., are peculiarly disposed to turn sour; and that saccharine fluids, such as the wort of brewers, are extremely apt to pass into the acetous fermentation.

143. The actual amount of influence, however, which Electricity exerts over a growing Plant or Animal, can scarcely be estimated.

It would, perhaps, be the most correct to say, that the state of Electric *equilibrium* is that which is generally most favourable; and we find that there is a provision in the structure of most living beings, for maintaining such an equilibrium,—not only between the different parts of their own bodies, but also between their own fabrics and the surrounding medium. Thus a charge given to any part of a Plant or Animal, is immediately diffused through its whole mass; and though Organized bodies are not sufficiently good conductors to transmit very powerful shocks without being themselves affected, yet a discharge of any moderate quantity may be effected through them, without any permanent injury,—and this more especially if it be made to take place slowly. Now the points on the surfaces of Plants appear particularly adapted to effect this transmission: thus a Leyden jar may be discharged by holding a blade of grass near it, in one-third of the time required to produce the same effect by means of a metallic point; and an Electroscope furnished with Vegetable points has been found to give more delicate indications of the electric state of the atmosphere, than any other. Plants designed for a rapid growth have generally a strong pubescence or downy covering; and it does not seem improbable that one purpose of this may be, to maintain that equilibrium between themselves and the atmosphere, which would otherwise be disturbed by the various operations of vegetation, and especially by the process of evaporation, which takes-place with such activity from the surface of the leaves.

144. There appears to be sufficient evidence that, during a highly electric state of the atmosphere, the growth of the young shoots of certain plants is increased in rapidity; but it would be wrong thence to infer that this excitement is useful to the process of Vegetation in general, or that the same kind of electric excitement universally operates to the benefit or injury of the Plant. From some experiments made a few years since, it would appear that potatoes, mustard and cress, cinerarias, fuchsias, and other plants, have their development, and, in some instances, their productiveness, increased by being made to grow between a copper and a zinc plate, connected by a conducting wire; while, on the other hand, geraniums and balsams are destroyed by the same influence. The transmission of a series of moderate sparks through plants, in like manner, has been found to accelerate the growth of some, and to be evidently injurious to others. It is not unreasonable to suppose, that, as a great variety of chemical processes are constantly taking-place in the growing plant, an electric disturbance, which acts as a stimulus to some, may positively retard others; and that its good or evil results may thus depend upon the balance between these individual effects. This would seem the more likely from the circumstance, that, in the process of Germination, the chemical changes concerned in which are of a simpler character, Electricity seems to

have a more decided and uniform influence. The conversion of the starch of the seed into sugar, which is an essential part of this change, involves the liberation of a large quantity of carbonic and of some acetic acid. Now as all acids are negative, and as like electricities repel each other, it may be inferred that the seed is at that time in an electro-negative condition; and it is accordingly found that the process of germination may be quickened, by connexion of the seed with the negative pole of a feeble galvanic apparatus, whilst it is retarded by a similar connexion with the positive pole. A similar acceleration may be produced by the contact of feeble alkaline solutions, which favour the liberation of the acids; whilst, on the same principle, a very small admixture of acid in the fluid with which the seed is moistened, is found to produce a decided retardation.

145. It is well known that Trees and Plants may be easily killed by powerful electric shocks; and that, when the charge is strong enough (as in the case of a stroke of lightning), violent mechanical effects,—as the rending of trunks, or even the splitting and scattering of minute fragments,—are produced by it. But it has also been ascertained, that charges which produce no perceptible influence of this kind, may destroy the life of Plants; though the effect is not always immediate. In particular it has been noticed, that slips and grafts are prevented from taking root and budding. There can be little doubt that, in these instances, a change is effected in the chemical state of the solids or fluids, although no structural alteration be perceptible.

146. In regard to the influence of Electricity upon the Organic functions of Animals, still less is certainly known; but there is evidence that it may act as a powerful stimulant in certain disordered states of them. Thus in Amenorrhœa, a series of slight but rapidly-repeated electric shocks will often bring-on the catamenial flow; and it is certain that chronic tumours have been dispersed, and dropsies relieved by the excitement of the absorbent process, through similar agency. In fact, there is strong reason to believe, that Electricity may be advantageously employed remedially in many states of disordered nutrition; in virtue of its power of modifying the operations of the Vital forces.

147. The closest relations of Electricity, however, are with the proper Animal functions; for these, as will be shown hereafter, are more directly and obviously subject to its influence, than are the Organic. Thus Electricity, when transmitted along a Nerve, whether sensory or motor, a nerve of 'special' or one of 'common' sensation, is capable of calling-forth all the actions of which that nerve is the instrument; and, when brought to bear on a Muscle, it immediately excites a contractile movement.—It is probably through the influence of this agent upon the Nervous system, that electric states of the atmosphere induce in certain individuals a

degree of languor and depression, which cannot be accounted-for in any other way. An instance is on record, in which the atmosphere was in such an extraordinary state of electric disturbance, that all pointed bodies within its influence exhibited a distinct luminosity; and it was noticed, that all the persons who were exposed to the agency of this highly-electrified air, experienced spasms in the limbs and an extreme state of lassitude.

148. Animals, like Plants, are liable to be killed by shocks of Electricity; even when these are not sufficiently powerful to occasion any *obvious* physical change in their structure. But, as formerly mentioned (§ 68), there can be no doubt that minute changes may be produced in their delicate parts, which are quite sufficient to account for the destruction of their vitality, even though these can only be discerned with the Microscope. The production of changes in the Chemical arrangement of their elements, is, however, a much more palpable cause of death; since it may be fully anticipated beforehand, and can easily be rendered evident. To take one instance only;—it is well known, that *albumen* is made to coagulate, *i. e.*, is changed from its soluble to its insoluble form, under the influence of an electric current; and it cannot be doubted that the production of this change in the fluids of the living body (almost every one of which contains albumen), though to a very limited extent, is quite a sufficient cause of death, even in animals that are otherwise most tenacious of life. "I once discharged a battery of considerable size," says Dr. Hodgkin, "through a common Earth-worm, which would in all probability have shown signs of life long after minute division. Its death was as sudden as the shock; and the semi-transparent substance of the animal was changed like Albumen which has been exposed to heat."

4. *Of Moisture, as a Condition of Vital Activity.*

149. Independently of the utility of Water as an article of *food*, and of the part it performs in the Chemical operations of the living body by affording two of their most important materials (oxygen and hydrogen), there can be no doubt that a certain supply of moisture is requisite, as one of the conditions without which no vital actions can go-on. It has been already remarked, indeed, that one of the distinguishing peculiarities of Organized structures, is the presence of solid and liquid component parts; and this in the minutest portions of the organism, as well as in the aggregate mass. And in all the *vital*, as well as in the *chemical* actions, to which these structures are subservient, the presence of liquid is essential. All nutrient materials must be reduced to the liquid form, before they can be assimilated by the solids; and, again, the solid matters which are destined to be carried-off by excretion, must be again reduced to the liquid state, before they can be thus withdrawn from

the body. The tissues in which the most active changes of a purely vital character are performed,—namely, the Nervous and Muscular,—naturally contain a very large proportion of water; the former as much as 80, and the latter 77, per cent. On the other hand, in tissues whose function is of a purely-mechanical nature, such as Bone, the amount of liquid is as small as is consistent with the maintenance of a certain amount of nutrient action in its interior. By the long-continued application of dry heat to a dead body, its weight was found to be reduced from 120 pounds to no more than 12; so that, taking the average of the whole, the amount of water, not chemically combined, but simply interstitial, might be reckoned at as much as 90 per cent. It is certain, however, that much decomposition and loss of solid matter must have taken-place in this procedure; and we shall probably estimate the proportion more accurately, if we regard the weight of the fluids of the Human body as exceeding that of the solids by six or seven times.

150. There is a great variation in this respect, however, among different tribes of living beings. There are probably no highly-organized Animals, whose texture contains *less* liquid than that of Vertebrata (unless, it may be, certain Beetles); but there can be no question that, among some of the Zoophytes, the proportion of solids to liquids is just the other way. In those massive coral-forming animals, which seem to have been expressly created for the purpose of uprearing islands and even continents from the depths of the ocean, we find the soft tissues confined to the surface, and all within of a rocky hardness. It is not, however, correct to say (as is commonly done), that the coral-polypes 'build up' these stony structures as habitations for themselves; for the stony matter is deposited, by an act of nutrition, in the living tissue of these animals, just as much as it is in the bones of Man. But the parts once consolidated henceforth remain almost dead, so far as the animal is concerned; they are not connected with the living tissues by any vessels, nerves, &c.; their density prevents them from undergoing any but a very slow change, so that they require and receive scarcely any nutrient materials; and they might be altogether removed, by accident or decay, without any direct injury to the still-active, because yet unconsolidated, portions of the polype-structure.

151. There is a close correspondence in this respect, between the condition of the stony or horny stem of a Coral, and the heart-wood of the trunk of a Tree; for the latter, becoming consolidated by internal deposit, for the purpose of affording mechanical support, is thenceforth totally unconnected with the vegetative operations of the tree, and might be removed (as it frequently is by natural decay) without affecting them. In all the parts in which the nutrient processes are actively going-on, do we observe that the tissue contains a large proportion of water; and that, if the succulent portions be dried-up, their vital properties are destroyed. Thus it is in the

soft tissue at the extremities of the radicles or root-fibres, that the function of absorption is performed with the greatest activity; so that these parts have received the name of *spongioles:* it is in the cells which form the soft parenchyma of the leaves, that the elaboration of the sap, the fixation of carbon from the atmosphere, and the preparation of the peculiar secretions of the plant take-place: and it is in the space between the bark and the wood, which is occupied (at the season of most active growth) by a saccharine glutinous fluid, that the formation of the new layers of wood and bark is effected. *Now, as soon as these parts* become consolidated, they cease to perform any active vital operations. *The spongioles, by the lengthening of the root-fibres, become converted into a portion* of those fibres, and *remain subservient merely to the transmission* of the fluids absorbed; the leaves gradually become choked by the saline and earthy particles contained in the ascending sap, which they have had no power of excreting, and they wither, die, and fall-off; and the new layers of wood and bark, when once formed, undergo but little further change, and are subservient to little else than the transmission of the ascending and descending sap to the parts where they are to be respectively appropriated.

152. There are some remarkable instances in both the Animal and Vegetable kingdoms, of an immense preponderance in the amount of the fluids over that of the solids of the structure. This is characteristic of the whole class of *Acalephæ* or 'jelly-fish,' giving to their tissues that softness from which their common name is derived; these animals, in consequence, are unable to live out of water; for when they are removed from it, a drain of their fluids commences, which soon reduces their weight to a degree that destroys their lives,—a Medusa weighing fifty pounds being thus dried-down to a weight of as many grains. The most remarkable instances of a parallel kind among Plants, are to be found in the tribe of *Fungi;* certain members of which are distinguished by an almost equally small proportion of solid materials in their textures, presenting a most delicate gossamer-like appearance to the eye, and possessing such little durability that they come to maturity and undergo decay in the course of a few hours. These are not inhabitants of the water, but will vegetate only in a very damp atmosphere.

153. As we find various Plants and Animals very differently constructed in regard to the amount of fluid contained in their tissues, so do we also find them dependent in very different degrees upon a constant supply of external moisture. There is no relation, however, between the succulence of a plant, and the degree of its dependence upon water; in fact, we commonly find the most succulent plants growing in the driest situations; whilst the plants which are adapted to localities where they can obtain a constant supply of fluid, are not usually remarkable for the amount of water in their own structure. This, however, is easily explained. We

find the most succulent plants,—such as the *Sedums* or 'stone-crops' of our own country, and the *Cacti* and *Euphorbiæ* of the tropics,—in dry exposed situations, where they seem as if they would be utterly destitute of nutriment. The fact is, however, that they lose their fluid by exhalation very slowly, in consequence of their small number of stomata; whilst, on the other hand, they absorb with great readiness during rainy weather, and are enabled, by the fleshiness of their substance, to store-up a large quantity of moisture until it may be required. In some parts of Mexico, the heat is so intense, and the soil and atmosphere so dry, during a large part of the year, that no vegetation is found at certain seasons, save a species of Cactus; this affords a wholesome and refreshing article of food, on which travellers have been able to subsist for many days together, and without which these tracts would form impassable barriers. On the other hand, the plants of damp situations usually exhale moisture almost as fast as they imbibe it; and consequently, if their usual supply be cut-off or diminished, they soon wither and die. Plants that usually live entirely submerged, are destitute of the cuticle or thin skin, which covers the surface in other cases; in consequence of this, they very rapidly lose their fluid, when they are removed from the water; and they are hence dependent upon constant immersion in it for the continuance of their lives, although their tissues may not be remarkable for the amount of fluid which they contain.

154. There are some Plants which are capable of adapting themselves to a great variety of situations, differing widely as to the amount of moisture which their inhabitants can derive from the soil and atmosphere; and we may generally notice a marked difference in the mode of growth, when we compare individuals that have grown under opposite circumstances. Thus a plant from a dry exposed situation shall be stunted and hairy, whilst another, of the same species, but developed in a damp sheltered situation, shall be rank and 'glabrous' (smooth). But in general there is a certain quantity of moisture congenial to each species; and the excess or deficiency of this condition has, in consequence, as great an influence in determining the geographical distribution of Plants, as the amount of light and heat. Thus, as already remarked, the Orchideæ and Tree Ferns of the Tropics grow best in an atmosphere loaded with dampness; whilst the Cactus tribe, for the most part, flourishes best in dry situations. The former become stunted and inactive, if limited in their supply of aërial moisture; whilst the latter, if too copiously nourished, become dropsical and liable to rot. Among the plants of our own country we find a similar limitation; a moist boggy situation being indispensable to the growth of some, whilst a dry exposed elevation is equally essential to the healthy development of others. There is a beautiful species of exotic Fern, the *Trichomanes speciosum*, the rearing of which has been frequently

attempted in this country and elsewhere, without success; but which only requires an atmosphere saturated with dampness for its healthy development, being easily grown in one of Mr. Ward's closed glass-cases. In this, as in similar examples, it is only necessary to imitate as closely as possible the conditions under which the species naturally lives; and sometimes this can only be accomplished, by surrounding the plant with small trees and shrubs, so as to give it a moister atmosphere than it could otherwise attain. Professor Royle mentions the growth, under such circumstances, of a fine specimen of the *Xanthochymus dulcis*, one of the *Guttiferæ* or Gamboge-trees, in the garden of the king of Delhi; this tree is naturally found only in the southern parts of India; and the success of its cultivation in this northerly situation is entirely due to its being sheltered by the numerous buildings within the lofty palace-wall, surrounded by almost a forest of trees, and receiving the benefit of perpetual irrigation from a branch of the canal which flows through the garden.

155. In regard to the influence of external moisture upon Animal life, there is much less to be said; since the mode in which fluid is received into the system is so entirely different. It may be remarked, however, that Animals habitually living beneath the water, like submerged Plants, are usually incapable of sustaining life for any length of time when removed from it, in consequence of the rapid loss of fluid which they undergo from their surface. It is, however, by the desiccation of the *respiratory* surface, preventing the due aëration of the blood, that the final result is for the most part occasioned; since we find that when there is a special provision to prevent this, as in the case of certain Fishes and Crustacea, the animals can quit the water for a great length of time. There can be no doubt that the amount of Atmospheric moisture is one of those conditions, which are collectively termed 'climate,' and which influence the geographical distribution of Animals, no less than that of Plants; but it is difficult to say how far the variations in moisture act alone. Every one, however, is conscious of the effect upon his health and spirits, of such variations as take place in the climate he may inhabit. The two principal modes in which these seem to operate, will be by accelerating or checking the exhalation of fluid from the skin and from the pulmonary surface; for when the air is already loaded with dampness, the exhaled moisture cannot be carried-off with the same readiness as when it is in a condition of greater dryness; and it will consequently either remain within the system, or it will accumulate and form sensible perspiration. It can scarcely be considered improbable, however, that the influence of moisture on the conducting power of the atmosphere for electricity, has something to do with its peculiar influence on the state of the nervous system.

156. Now each of these states may be salutary, being the one

best adapted to particular constitutions, or to different states of the same individual. A cool drying wind shall be felt as invigorating to the relaxed frame, as it is chilling to one that has no warmth or moisture to spare; on the other hand, a warm damp atmosphere, which is refreshing to the latter, shall be most depressing to the former. All who have tried the effect of closely-fitting garments impervious to moisture, are well aware how oppressive they soon become; this feeling being dependent upon the obstruction they occasion to the act of perspiration, by causing the included air to be speedily saturated with moisture. When the fluids of the system have been diminished in amount, either by the suspension of a due supply of water, or by an increase in the excretions, there is a peculiar refreshment in a soft damp atmosphere, or in a warm bath, which allows the loss to be replaced by absorption through the general cutaneous surface. The reality of such absorption has been placed beyond all doubt, by observations upon men who had been exposed to a hot dry air for some time, and afterwards placed in a warm bath; for it was found that the system would by this unusual means supply the deficiency, which had been created by the previous increase in the transpiration.

157. The effect of a moist or dry atmosphere, then, upon the Animal body, cannot be by any means unimportant; although, as we shall hereafter see, there exists in it a series of the most remarkable provisions for regulating the amount of its fluids. The influence of atmospheric moisture, however, is most obvious in disordered states of the system. Thus in persons who are subject to the form of Dyspepsia called atonic, which is usually connected with a generally-relaxed condition of the system, a very perceptible influence is experienced from changes in the quantity of atmospheric moisture; the digestive power, as well as the general functions of the body, being invigorated by dryness, and depressed by damp. Again there is no doubt that, where a predisposition exists to the Tuberculous Cachexia, it is greatly favoured by habitual exposure to a damp atmosphere, especially when accompanied by cold: indeed it would appear, from the influence of cold damp situations upon animals brought from warmer climates, that these two causes may induce the disease, in individuals previously healthy. On the other hand, there are some forms of pulmonary complaints, in which an irritable state of the mucous membrane of the bronchial tubes has a large share; when this irritation presents itself in the *dry* form, a warm moist atmosphere is found most soothing to it; whilst a drier and more bracing air is much more beneficial, when the irritation is accompanied by a too copious secretion.

158. Although, as already stated, no vital actions can go-on without a reaction between the *solids* and *fluids* of the body, yet there may be an entire loss of the latter, in certain cases, without necessarily destroying life; the structure being reduced to a state

of dormant vitality, in which it may remain unchanged for an unlimited period; and yet being capable of renewing all its actions, when moisture is again supplied. Of this we find numerous examples among both the Vegetable and the Animal kingdoms. Thus the Mosses and Liverworts, which inhabit situations where they are liable to occasional drought, do not suffer from being (to all appearance) completely dried up; but revive and vegetate actively, as soon as they have been thoroughly moistened. Instances are recorded, in which Mosses that have been for many years dried-up in a Herbarium, have been restored by moisture to active life. There is a *Lycopodium* (club-moss) inhabiting Peru, which, when dried-up for want of moisture, folds its leaves and contracts into a ball; and in this state, apparently quite devoid of animation, it is blown hither and thither along the surface by the wind. As soon, however, as it reaches a moist situation, it sends-down its roots into the soil, and unfolds to the atmosphere its leaves, which, from a dingy brown, speedily change to the bright green of active vegetation. The *Anastatica* (rose of Jericho) is the subject of similar transformations; contracting into a ball, when dried-up by the burning sun and parching air; being detached by the wind from the spot where its slender roots had fixed it, and rolled over the plains to indefinite distances; and then, when exposed to moisture, unfolding its leaves, and opening its rose-like flower, as if roused from sleep. A blue Water-Lily abounds in several of the canals at Alexandria, which at certain seasons become so dry, that their beds are burnt as hard as bricks by the action of the sun, so as to be fit for use as carriage-roads; yet the plants do not thereby lose their vitality; for when the water is again admitted, they resume their growth with redoubled vigour.

159. Among the lower Animals, we find several of considerable complexity of structure, which are able to sustain the most complete desiccation. This is most remarkably the case in the common *Wheel-Animalcule;* which may be reduced to a state of most complete dryness, and kept in this condition for any length of time, and which will yet revive immediately on being moistened. The same individuals may be treated in this manner, over and over again. Experiments have been carried still further with the allied tribe of *Tardigrades;* individuals of which have been kept in a vacuum for thirty days, with sulphuric acid and chloride of calcium (thus suffering the most complete desiccation the Chemist can effect), and yet have not lost their vitality. It is singular that in this desiccated condition, they may be heated to a temperature of 250°, without the destruction of their lives; although, when in full activity, they will not sustain a temperature of more than from 112° to 115°. Some of the minute Entomostracous Crustacea, which are nearly allied to the Rotifera, appear to partake with them in this curious faculty. Many instances are on record, in which Snails and other terrestrial

Mollusks have revived, after what appeared to be complete desiccation; and the *eggs* of the Slug, when dried-up by the sun or by artificial heat, and reduced to minute points only visible with the Microscope, are found not to have lost their fertility, when they are moistened by a shower of rain or by immersion in water, which restores them to their former plumpness. Even after being treated eight times in this manner, such eggs have been hatched when placed in favourable circumstances; and even eggs in which the embryo was distinctly formed, survived such treatment without damage.—That such capability should exist in the animals and eggs just mentioned, shows a remarkable adaptation to the circumstances in which they are destined to exist; since, were it not for their power of surviving desiccation, the races of Wheel-Animalcules and Entomostraca must speedily become extinct, through the periodical drying-up of the small collections of water which they inhabit; and a season of prolonged drought must be equally fatal to the terrestrial Mollusca.

160. It would seem that many cold-blooded animals are reduced, by a moderate deficiency of fluid, to a state of torpidity closely resembling that induced by cold; and hence it is, that during the hottest and driest part of the tropical year, there is almost as complete an inactivity as in the winter of temperate regions. The common Snail, if put into a box without food, constructs a thin operculum or partition across the orifice of the shell, and attaches itself to the side of the box: in this state it may remain dormant for years, without being affected by any ordinary changes of temperature: but it will speedily revive if plunged in water. Even in their natural haunts, the terrestrial Mollusks of our own climates are often found in this state during the summer, when there is a continued drought; but with the first shower they revive and move about. In like manner, it is observed that the rainy season between the tropics brings-forth the hosts of Insects, which the drought had caused to remain inactive in their hiding-places. Animals rendered torpid by deficiency of moisture, seem to have a tendency to bury themselves in the ground, like those which are driven to winter-quarters by cold. Mr. Darwin mentions that he observed with some surprise at Rio de Janeiro, that, a few days after some little depressions had been changed into pools of water by the rain, they were peopled by numerous full-grown shells and beetles.

161. This torpidity consequent upon drought is not confined to Invertebrated animals. There are several Fish inhabiting fresh water, which bury themselves in the mud when their streams or pools are dried-up, and which remain there in a torpid condition until they are again moistened. This is the case with the curious *Lepidosiren*, which forms so remarkable a connecting link between Fishes and the Batrachian Reptiles: it is an inhabitant of the upper

parts of the river Gambia, which are liable to be dried-up during much more than half the year; and the whole of this period is spent by it in a hollow which it excavates for itself deep in the mud, where it lies coiled-up in a completely torpid condition,—whence it is called by the natives the 'sleeping-fish.' When the return of the rainy season causes the streams to be again filled, so that the water finds its way down to the hiding-place of the Lepidosiren, it comes-forth again for its brief period of activity; and with the approach of drought, it again works its way down into the mud, which speedily hardens around it into a solid mass. In the same manner, the *Proteus* (§ 670), when the underground lakes it inhabits are periodically dried-up, retires to the passages that connect them, where it is believed to remain in a torpid condition; and it thence emerges into the lakes, as soon as they again become filled with water. The Lizards and Serpents, too, of tropical climates, appear to be subject to the same kind of torpidity in consequence of drought, as that which affects those of temperate regions during the cold of winter. Thus Humboldt has related the strange accident of a hovel having been built over a spot, where a young Crocodile lay buried, alive though torpid, in the hardened mud; and he mentions that the Indians often find enormous Boas in the same lethargic state, and that these revive when irritated or wetted with water.—All these examples show the necessity of a fixed amount of fluid, in the Animal structure, for the maintenance of vital *activity:* whilst they also demonstrate, that the preservation of the vital *properties* of that structure is not always incompatible with the partial, or even the complete, abstraction of that fluid; the solid portions being then much less liable to decomposition by heat, or by other agencies, than they are in their ordinary condition.

CHAPTER III.

OF THE ELEMENTARY PARTS OF ANIMAL STRUCTURES.

162. In the investigation of the operations of a complex piece of Mechanism, and in the study of the forces which combine to produce the general result, experience shows the advantage of first examining the component parts of the Machine,—its springs, wheels, levers, cords, pulleys, &c.,—determining the properties of their materials, and ascertaining their individual movements. When these have been completely mastered, the attention may be directed to their combined actions: and the bearing of these combinations upon each other, so as to produce the general result, would be the last object of study.

163. This seems the plan which the Student of Physiology may most advantageously pursue, in the difficult task of making himself acquainted with the operations of the living Organism, and with the mode in which they concur in the maintenance of Life. He should first examine the properties of the component materials of the structure, in their simplest form: these he will find in its nutrient fluids. He may next proceed to the simplest forms of organized tissue, which result from the mere solidification of those materials in the form of fibres, and whose properties are chiefly of a mechanical nature. From these he will pass to the consideration of the structure and actions of those tissues that consist chiefly of cells; and will investigate the share they take in the strictly vital operations of the economy. Next his attention will be engaged by the tissues produced by the transformation of fibres and cells; of which some are destined chiefly for affording mechanical support to the fabric, and others for peculiar vital operations. And he will be then prepared to understand the part which these elementary tissues severally perform in the more complex organs.—A due knowledge of these elementary parts, and of their physical, chemical, and vital properties, is essential to every one who aims at a *scientific* knowledge of Physiology. True it is, that we may study the *results* of their operations, without acquaintance with them; but we should know nothing more of the *working* of the machine, than we should know of a cotton-mill, into which we saw cotton wool entering, and from which we saw woven fabrics issuing forth; or of a paper-making-machine, which we saw fed at one end with rags, and discharging hot-pressed paper, cut into sheets, at the other. The study of these results affords, of course, a very important part of the knowledge we have to acquire respecting the operations of the machine; but we could learn very little from them alone, regarding the nature of the separate processes effected by it; still less should we be prepared, by any disorder or irregularity that might present itself in the general results, to seek-for and to rectify the cause of that disturbance in the working of the machine, by which the abnormal result was occasioned.

164. Now just as in a Cotton-mill there are machines of several different kinds, adapted to effect different steps of the process by which the raw material is converted into the woven fabric; so do we find that in the complex Animal fabric there is a great variety of *organs* for performing those several changes, by which the fabric itself is built-up and maintained in a condition fit for the performance of its peculiar operations. These operations are the phenomena of sensation, of spontaneous motion, and of mental action. They are the great objects of *Animal* existence; just as the combination of elements into organic substances, that are to furnish the materials of the Animal fabric, seems to be the great purpose of *Vegetable* Life. The vital phenomena which are peculiar to

Animals, are manifestations of the properties of certain forms of organized matter,—the Nervous and Muscular tissues,—which are restricted to themselves; just as those that are common to Animals and Plants, are effected by organized structures which are found alike in both kingdoms. Here, then, we have one essential distinction between these kingdoms;—namely the presence in Animals of a peculiar apparatus, and the consequent possession by them of peculiar endowments, which are totally wanting in Plants. There are, it is true, many species, indeed whole tribes, in which it is impossible to say with certainty, how far sensibility and spontaneity of action may be justly inferred from the movements they exhibit; so that, their structure being so simple as to afford no distinctive characters, our assignment of them to the Animal or to the Vegetable kingdom must be determined entirely by the mode in which they obtain the materials of their nutrition (§§ 60, 61).

165. All the operations, then, which are common to Animals and Plants, are concerned in the building-up of the organized fabric, in the maintenance of its integrity, and in the preparation of the germs of new structures, to compensate for the loss of the parent by death. These operations, as formerly explained (§ 36), involve a series of very distinct processes; which, though all performed by the simple cell of the humblest plant, are distributed in more complex structures through a number of parts or organs. The case is not remotely analogous to that of the peasant-woman, who draws the thread with her simple wheel, to produce which all the elaborate mechanism of the cotton-mill is arranged; that simple wheel answering in her hands the same purpose with a complex assemblage of machines, among which the several stages of the process are distributed, when the greatest productive power is desired. In the most highly-organized bodies, we find the principle of 'division of labour' carried-out to its utmost extent; for the entire organism consists of a number of dissimilar parts, each of them adapted to some different action; yet these actions are devised with such reference to each other, that their whole assemblage (as in the case of the cotton-mill) concurs in one common end. Further, as in each of the machines of the cotton-mill we may have similar elements,—such as wheels, levers, pulleys, bands, &c.,—put together in different methods, and consequently adapted for different purposes, as carding, spinning, weaving, &c., so shall we find in the animal body, that these different organs are composed of very similar elements, and that the individual actions of these elementary parts are the same; but that the difference of result is the consequence of the variety in their arrangement. Thus we shall find that the power possessed by cells to select and draw into themselves certain components of the surrounding fluids, and their subsequent liberation of these selected products, are means employed in one part of the body to introduce nutrient materials into the current of

the circulation, whilst in another the same processes are used as means to withdraw, from that very same current, certain substances of which it is necessary to get rid. Now certain combinations of elementary structure, adapted to the performance of a set of actions tending to one purpose, and thus resembling one of the machines of a cotton-mill, is termed an *organ;* and the sum-total of its actions is termed its *function.* Thus we have in the function of Respiration, which essentially consists of an interchange of oxygen and carbonic acid between the air and the blood, a multitude of distinct changes, some of them of a character apparently not in the least related to it, but all necessary, in the higher and more complex fabric, to bring the blood and the air into the necessary relation. The sum-total of these changes constitutes the *function* of Respiration; and the structures by which they are effected are *organs* of Respiration.

166. The entire Organized structure, then, may be regarded as made up of distinct *organs*, having their several and (to a certain extent) independent purposes; and these organs may be resolved, in like manner, into simple *elementary parts*, whose structure and composition are the same, in whatever part of the fabric they occur. And in like manner, the phenomena of Life, considered as a whole, may be arranged under several groups or *functions*, according to the immediate purpose to which they are directed; and yet in every one of these groups, we shall find repeated the same *elementary changes* which are concerned in the rest. Thus in the act of Respiration, the same kind of muscular movements, the same sort of nervous agency, are concerned, as contribute to the ingestion of the food; together with a circulation of blood, similar to that which supplies the materials for the nutrition of the tissues.—Hence we see the propriety of applying ourselves first to the consideration of the elementary parts of the living structure, and of the properties by which they effect the changes that are characteristic of its several organs.

1. *Of the Primary Components of the Animal Fabric.*

167. As we can best study the primary components of the Animal fabric, by investigating their properties before the process of Organization begins, or whilst it is taking place, we must have recourse for this purpose to the nutrient fluid,—the Blood; in which these *histogenetic* or tissue-forming substances are contained in the state most completely prepared for the reception of the vitalizing influence. The same substances may be found, in a yet earlier stage of preparation, in the Chyle and Lymph; and also in the Eggs of oviparous animals. The circumstances attending the development of the latter afford, indeed, the most satisfactory proof of the convertibility of the simple chemical product, Albumen, with certain

inorganic substances, into every form of organized structure. For the *white* of the egg consists of nothing else than albumen, combined with phosphate of lime; whilst the *yolk* is chiefly composed of the same substance, mingled with oily matter, and a minute quantity of sulphur, iron, and some other inorganic bodies. Yet this albumen and fatty matter are converted, after the lapse of a few days, under the agency of an elevated temperature upon the germ, into a complex fabric, composed of bones, muscles, nerves, tendons, ligaments, cartilages, fibrous membranes, fat, cellular tissue, &c., and endowed with the properties characteristic of all these substances, which, when brought into consentaneous activity, manifest themselves in the life of the chick.—In tracing these wonderful transformations, therefore, we should rightly commence with *Albumen*, and the compounds most nearly allied to it, which constitute the group of *Albuminoid substances.**

168. All the *Albuminoid substances* or 'protein-compounds' occur under two conditions, namely, in a *soluble*, and in an *insoluble* or scarcely-soluble state; it is in the former that we find them naturally existing in the animal fluids. The soluble modification, when dried, forms a faint yellow, translucent, friable mass, having no smell or peculiar taste; it dissolves in water, but is insoluble in alcohol and ether; it is precipitated by alcohol from the aqueous solution, after which it is usually insoluble in water. The aqueous solution is precipitated by most metallic salts, and the precipitate generally contains the acid and base of the salt employed, in addition to the protein-compound. The greater number cannot be precipitated from their aqueous solution by alkalies, or by most of the vegetable acids; but they are precipitated by mineral acids (with the exception of ordinary phosphoric acid) and by tannic acid; and by some of these they are converted into their insoluble form. Into this, moreover, the greater number of them are changed by boiling; and it is in this mode that their insoluble forms are commonly obtained.—The insoluble compounds, when dried, are white and pulverizable, without taste or smell, without reaction on vegetable colours, and insoluble in water, alcohol, ether, and all indifferent menstrua; but they are all more or less readily dissolved by *alkalies*, from which they may be precipitated by mere neutralization with acids. Their behaviour towards different *acids* is by no means so uniform, and must be separately described in each case. All of them, however, are acted-on in a peculiar manner by concentrated Nitric and Hydrochloric acids; the former giving them

* These substances are not unfrequently termed 'protein-compounds': it having been affirmed by Mulder that they are formed by the union of sulphur and phosphorus in different proportions with a common organic base, to which, as the foundation of the whole series of histogenetic compounds, the name of *protein* was thought appropriate. Although it has been proved that this idea is erroneous, yet the general term founded upon it is still frequently employed.

when heated a deep *lemon-coloured* tint; whilst the latter causes them to assume a gradually-increasing *blue* colour, which becomes intense when they are exposed to warmth and air. Again, they are all dissolved by concentrated acetic acid and other organic acids, as well as by phosphoric acid; and are precipitated from these solutions by ferrocyanide of potassium.—All the protein-compounds contain Sulphur, which seems to be one of their essential constituents, not being capable of entire separation without the complete destruction of the organic substance, although a part may be withdrawn by digestion with fixed alkalies.

169. All the Protein-compounds are very liable to decomposition; this change taking place in them spontaneously, when they are exposed to the air at ordinary temperatures; and being very readily induced by oxidising agents, alkalies, &c., the effect of which is promoted by heat. As yet, however, no satisfactory clue has been obtained to the very complex composition of these substances; since they cannot be resolved by analysis (like complex inorganic bodies) into two or more compounds whose synthesis reproduces the original. Still it is very interesting to observe, that whilst the ultimate decomposition of the protein-compounds resolves them (with oxygen taken from the atmosphere) into water, carbonic acid, and ammonia, various organic compounds may be generated by a less complete separation of their components. Thus by the action of oxidising substances, the formic, acetic, butyric, caproic, and other organic acids of the same group, which occur naturally in the animal body, may be obtained; and there is a strong probability that the ordinary fatty acids (§ 260) may be generated by a similar change.—Again, by the prolonged action of caustic alkalies upon the protein-compounds, a crystalline substance is obtained, which is termed *Leucine;* this forms colourless scales, destitute of taste and odour; it is soluble in water, and sublimes unchanged. It consists of 12C, 12H, 1N, 4O. There is not at present any evidence that this substance is ever produced in the living body; but a strong interest attaches to it, from the fact that it may be procured from Gelatine, as well as from the Protein-compounds. Another compound obtained by the same reaction is called *Tyrosine;* it crystallizes in brilliant needles; and its formula is 16C, 9H, 1N, 5O.—The tendency to decomposition which exists in this class of substances, not merely occasions the re-arrangement of their own elements in new compounds of a different character, but also tends to produce similar changes in other substances (§§ 466, 471); and it is probable that this kind of agency takes-place to a great extent in the living body. This property makes it very important that the history of the protein-compounds in the living body should be fully made-out; since it is obvious that they are not merely required as histogenetic materials, but that they also take an important part in the transformation of other substances by their action as *ferments.*

170. Of the whole series of protein-compounds, *Albumen* is obviously the one which may be considered as the proper *pabulum* of the Animal tissues generally; since we have seen that from it, in combination with fatty matter and mineral ingredients, all the tissues of the body may be generated (§ 167). We shall find, moreover, that the other histogenetic substances, when employed as food, must be reduced to the state of albumen, before they can be appropriated by the living system. The properties of Albumen may be studied in the white of the egg, or in the serum of the blood, from either of which situations it may be obtained in a nearly pure state by very simple means. These two forms of it, however, are not precisely identical; indeed it appears from recent inquiries, that striking differences are produced in albumen, not merely by the presence of some other body, such as an alkali or a salt, but by the different proportions in which this occurs; and hence it is that various and contradictory statements have been made, in reference to the properties of this substance. The following are the facts of most physiological interest.—In the before-mentioned animal fluids, as well as in several others, Albumen exists in its soluble form, but not in an isolated state; for it is united with soda, as an acid to its base, and thus may be formed a basic, neutral, or acid albuminate of soda. The *basic* compound, which contains about $1\frac{1}{2}$ per cent. of soda, and gives a slightly alkaline reaction, is the one which ordinarily presents itself in normal blood, as well as in the egg; it is far more soluble in water than is pure albumen, which, indeed, when *entirely* separated from all other substances, is probably not soluble at all; and it differs from pure albumen, moreover, in the mode in which it coagulates on the application of heat, for whilst the latter separates in flakes, sodo-albumen forms a white gelatinous mass, or, if the fluid be much diluted, makes itself apparent only by a milky or opalescent turbidity. A moderately-strong solution of pure albumen in water becomes turbid at 140°, becomes completely insoluble at 145°, and separates in flakes at 167°: when excessively diluted, however, no turbidity can be produced by a less heat than 194°; and coagula will only separate after it has been boiled a considerable time. After having been dried *in vacuo*, however, or at a temperature below 120°, albumen may be heated to 212° without passing into the insoluble condition.* Albumen may be precipitated from an aqueous solution by diluted alcohol; but it does not pass into the insoluble form, unless a large quantity of strong alcohol be added. It is also precipitated by creosote. Albumen is converted into the insoluble form by most acids; but it

* This fact is of much interest in relation to the experiments of Doyère and others upon the tenacity of life of the Tardigrade tribe of Rotifera (§ 159); for it has been found that, *when completely desiccated*, the bodies of these animals might be exposed to a heat of 250°, without the destruction of their vitality.

is not precipitated by the mineral acids, unless they are added in excess; and the organic acids, with the exception of the tannic, do not throw it down. It is converted into the insoluble form by alkalies, but is not precipitated by them, being held-up by their presence. The greater number of metallic salts precipitate albumen, which generally passes into the insoluble state, and enters into combination, either with the basic salt itself, or with its acid and its base separately; one of these salts, the albuminate of the chloride of mercury, is of much interest, as being that which is produced by the mixture of a solution of albumen with one of corrosive sublimate.

171. The following is the composition of Albumen, according to the most recent analyses of two eminent chemists.

	Scherer.	*Mulder.*
Carbon	54·9	53·5
Hydrogen	7·0	7·0
Nitrogen	15·7	15·5
Oxygen	22·4	22·0
Sulphur		1·6
Phosphorus		0·4
	100·0	100·0

This, according to Liebig, may be represented (omitting the sulphur and phosphorus) by the formula 49 Carbon, 36 Hydrogen, 14 Oxygen, 6 Nitrogen. It seems probable that Phosphorus is not (like Sulphur) a true constituent of Albumen, or of any of the Protein-compounds; as it may be entirely separated from them, without the destruction of their integrity.* Albumen seems never to occur in the animal body, except in such intimate union with fatty and mineral substances, that it is with difficulty separated from them. The quantity of these is variable; but altogether they usually amount to at least 6 per cent., of which from 1 to 2·5 per cent. consists of phosphate of lime.—As a general rule, Albumen is found in all the *nutritive fluids* of the body, as the Blood, the Chyle, the Lymph, and the serous exudation which percolates through the interstices of the tissues. From several of the *tissues*, also, it may be obtained in considerable abundance; but it is not always easy to say whether it is a natural constituent of such tissues, or whether it is simply left by the fluid with which they were charged. It cannot be said that Albumen is a normal constituent of any of the *secreted* fluids, such as the salivary, gastric, or pancreatic; the peculiar organic constituents of these being apparently albuminous substances in a state of change. And among the proper *excretory* matters, it is certain that albumen is never found but in consequence of morbid action; its appearance indicating either disease of the excreting organ, or a marked alteration either in the composition of the blood or in the mode of its circulation.

* See Prof. Liebig's "Familiar Letters on Chemistry," pp. 437 and 451.

172. Nearly allied to Albumen is the substance termed *Casein*, which replaces it in Milk; and this is specially worthy of notice here, because it is the sole form in which the young Mammal receives albuminoid nutriment into its body, during the period of lactation. Like Albumen, this substance may exist in two forms, the soluble, and the insoluble or coagulated; and it further agrees with it, in requiring, as a condition of its solubility, the presence of a free alkali, of which, however, a very small quantity suffices for the purpose. It differs from Albumen, however, in this; that it does *not* coagulate by heat, and that it *is* precipitated from its solution by Acetic acid. Casein is further remarkable for the facility with which its coagulation is effected by the contact of certain animal membranes, as in the ordinary process of cheese-making. It is uncertain whether there is any essential difference in composition between Casein and Albumen, or whether they are 'isomeric' compounds having the same elementary composition. In their coagulated state, they scarcely differ in properties. Casein appears to be readily converted into Albumen in the digestive process; being coagulated, when introduced in the liquid form, by the gastric fluid, and then dissolved by it. Casein appears even to surpass Albumen in its power of combining with the phosphates of lime and magnesia, and of rendering them soluble; as much as 6 per cent. of phosphate of lime being usually obtainable from it. A substance resembling casein is obtainable from the serum of the blood; being met-with in unusually large proportion in the blood of pregnant females and especially in that of the placenta. Casein is also found in the serous liquid which is diffused through the tissues, especially that of the muscles and of areolar tissue. It is found also, mingled with albumen, in the yolk of the egg; this mixture has been known under the distinctive name of *vitellin*. All the liquids containing Casein are such as appear to have it for their special function to supply formative materials for rapidly-growing tissues; and we are therefore in all probability to regard this substance as still more closely related to them, than is albumen itself.—There is every reason to believe, however, that, for the formation of all the Animal tissues, the presence of fatty matter, as well as of an albuminous compound, is essential; and it is a circumstance worthy of note, that in both the foregoing cases, fatty matter is mingled with the albumen or casein, in the aliment destined for the development of the young animal. This subject, however, will be more fully discussed hereafter.

173. The substance of which Muscles are composed, has been commonly considered to be fibrin; but it differs essentially from fibrin in its properties (being at least as much allied to albumen), and is now distinguished as *Syntonin*. Its special chemical peculiarity is its solubility in very dilute hydrochloric acid (1 part to

100 of water) and its precipitation in the form of a jelly when the acid is neutralized; this jelly forms, with lime-water or very dilute alkaline solutions, a solution which coagulates by heat; and thus it seems to be reduced nearly to the condition of Albumen. This is, in fact, very much what takes-place in the act of digestion of flesh-meat; the muscle-substance being first dissolved by the hydrochloric acid of the gastric fluid, and the solution being then rendered alkaline by the mixture of bile and other secretions in the small intestine.

174. The Animal derives the materials of its nutrition, however, not only from the Albuminous compounds furnished by flesh, eggs, and milk, but also from those which are supplied by the Vegetable kingdom. Every growing Plant, as already mentioned (§ 12), forms albuminous compounds by the combination of inorganic elements, as the pabulum of its own tissues; but many Plants generate these in much larger proportion, and store them up in their cells; and it is from such, that Animals derive their largest supply of nutritive material. Thus the *gluten* of wheat, or the tenacious mass which is left after the removal of the starch by washing, is principally composed of a substance which is closely allied in composition and properties to the Albumen of animals; being moderately soluble by water, coagulated by heat, and precipitated by acids (except the phosphoric and acetic) and by metallic salts; and this is designated *Vegetable Albumen*. From the seeds of Leguminous plants a substance termed *Legumin* may be separated, which corresponds with Casein in not being precipitated by heat; hence it is sometimes designated as *Vegetable Casein*.—Various other modifications of the albuminous principle are found in Plants; but the foregoing are the most important in their relations to the nutrition of Animals. Like flesh, cheese, &c., they are reduced by the digestive process to the state of soluble Albumen; and in this form they are taken up, and carried into the circulation.

175. The fluids that are formed at the expense of the Albuminous matters which have been digested and absorbed, contain a substance, which is so closely related to Albumen in its ultimate Chemical composition, as not to be distinguishable from it with any degree of certainty,* but which, though still fluid

* According to some analyses, Fibrin differs slightly from Albumen in ultimate composition, especially in the larger proportion borne by its oxygen to the other constituents; the ratios of its several constituents in 1000 parts being as follows:—Carbon 546, Hydrogen 70, Oxygen 220, Nitrogen 157, Sulphur 4, and Phosphorus 3. The difference in their *vital* relations, however, is far greater than any such difference in their *chemical* composition can account-for, and can only be justly attributed to the forces brought to act upon the fibrin during its circulation in the vessels of the living body. It has been recently maintained, that Fibrin is not to be regarded (as here represented) as Albumen in the transition-stage of incipient organization, but that it is a product of the disintegration of the tissues, only received-back into the

whilst circulating in the living vessels, exhibits a decided tendency to assume the *organized* form, and manifests properties which are so different from those of inorganic matter, that they must be regarded as *vital*. This substance is *Fibrin*. It is found in the Chyle, or crude blood, soon after this is taken-up from the food; it presents itself in gradually-increasing proportion, as the Chyle slowly passes along the Lacteal vessels, and through the Mesenteric glands, towards the termination of the Absorbent system in the Venous; and it is also found in the fluid contents of that other division of the Absorbent system, the Lymphatic apparatus, which is distributed through the body at large, and which seems to have for its chief office to take-up, and to re-introduce into the circulating current, such particles contained in the fluids of the tissues, as do not require to be at once cast-out of the body, but may be again employed in the process of Nutrition. But it is found, above all, in the Blood; the fluid whose ceaseless and rapid course through the body supplies to every element of the structure the materials of its growth and development: and the varying proportions in which it presents itself there, are evidently closely connected with the formative powers of that fluid. It is also a principal element of certain colourless *exudations*, which are poured-forth from wounded or inflamed surfaces, or which are deposited in the interstices of inflamed tissues; these exudations, when possessed of a high formative property (that is, a readiness to produce an organized tissue), are said to be composed of *coagulable* or *organizable lymph*, which is nothing more than the fibrinous element of the blood, in an unusually concentrated state.—We shall first notice the Chemical properties of Fibrin; and shall then inquire into those which present the first dawnings or indications of Vitality.

176. Like the other Protein-compounds, *Fibrin* may exist in solution, or in an insoluble form; but there is this important difference,—that its soluble form is not a permanent one, and cannot be maintained in any fibrinous fluid that has been drawn from the living vessels, without the influence of re-agents which totally destroy its peculiar properties. All investigations of a Chemical nature, therefore, must be made upon insoluble Fibrin; and this may be obtained in its purest state, by whipping fresh blood with a bundle of twigs, by which operation it will be caused, in coagulating, to adhere to the twigs in the form of long, white, elastic filaments, with scarcely an admixture of foreign matter. It differs from Syntonin or muscle-substance, as from other albuminoid compounds, in not being dissolved by water acidulated with 1 per

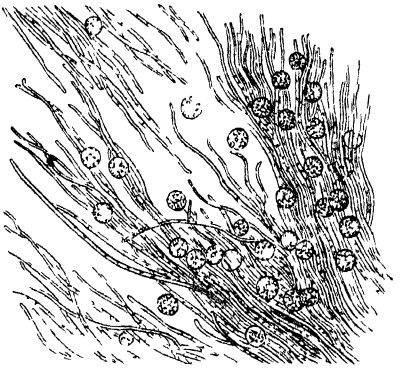
blood in order that it may be carried out of the system through the excretory channels.—For a discussion of this hypothesis, see the "Brit. and For. Med.-Chir. Review," vol. vii. pp. 153, 473, and the Author's "Princ. of Hum. Physiol.," 5th Ed., §§ 208, 209.

cent. of hydrochloric acid, being merely caused to swell-up into a gelatinous mass, which contracts again when more acid is added. When dried in vacuo, or at a gentle heat, it becomes translucent and horny; and in this condition, it closely resembles coagulated albumen. It further resembles that substance, in being soluble in very dilute caustic alkali, and in phosphoric acid; and the solutions exhibit many of the properties of the similar solutions of albumen. When the Fibrin of venous blood is triturated in a mortar with a solution of nitrate of potash, and the mixture is left for twenty-four hours or more at a temperature of from 100° to 120°, it becomes gelatinous, slimy, and eventually entirely liquid. In this condition, it exhibits all the properties of a solution of Albumen which has been neutralized by acetic acid. It coagulates by heat; it is precipitated by alcohol, corrosive sublimate, &c.; and, when largely diluted, it deposits a flocculent substance, not to be distinguished from insoluble albumen. The Fibrin of arterial blood, however, cannot be reduced to the fluid form by solution with nitre; and this appears to be due to its oxidized condition; for in a solution of Venous fibrin in nitre, contained in a deep cylindrical jar, and having its surface freely exposed to the air, a fine flocculent precipitate is gradually seen to form; and this, when collected, is found to have the properties of arterial fibrin. Fibrin, like Albumen, unites with acids as a base, forming definite compounds; and with bases as an acid. It also possesses the property of uniting with the earthy phosphates; of which from 0·7 to 2·5 per cent. are found in the ash that is left after its combustion.—There can be no doubt that it is formed in the blood, and in the other fluids in which it presents itself, at the expense of Albumen; and though we know little of the means by which this transformation is effected, yet several circumstances point to the conclusion that a higher degree of oxidation is an essential condition of the change.

177. We see, then, that when considered in its simply-Chemical relations, Fibrin is very closely related to Albumen; and that the chief point of obvious variation, is the *spontaneous* coagulation of the former, when it is removed from the living body. There is, however, in the structure of the coagulum itself, a most important difference; for instead of consisting of a homogeneous structureless mass, or of a simple aggregation of minute granules, it is found by the Microscope to possess a definite *fibrous* arrangement, the fibres crossing one another in every direction. In the ordinary coagulum or clot of Blood, these fibres do not present any great degree of firmness; they may be hardened, however, by boiling; and their arrangement then becomes more definite. They may be seen much more clearly, however, in the 'buffy coat' of Inflammatory blood (Fig. 2), in which there is not only an increased proportion of Fibrin, but the Fibrin itself seems to have undergone a higher

elaboration, that is, to have proceeded still further in the change towards regular organization. In this state, the process of coagula-

*Fig. 2.**



tion is unusually slow; the clot formed by the fibrous tissue is much more solid; and it continues for some hours, or even days, to increase in firmness, by the mutual attraction of the particles composing the fibres, which causes them to contract and to expel the fluid contained in their interstices.

Fig. 3 †



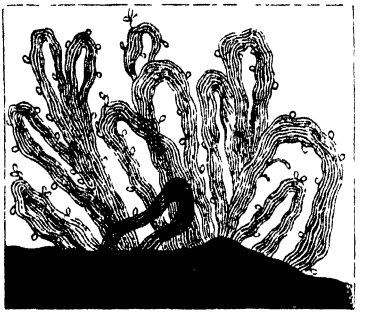
178. The most perfect fibrous structure originating in the simple coagulation of fibrin, is to be found, however, in those exudations, which take-place either from inflammation, or from a peculiar formative action, destined to repair an old tissue or to produce a new one. Thus in Fig. 3 is shown the appearance of the 'nucleated blastema' effused into the theca of a tendon divided by subcutaneous incision; in which an incipient *fibrillation* is seen. A more advanced stage of this process is shown in Fig. 4, which represents the fibrous structure of a false membrane, formed by the consolidation of a fibrinous exudation from the surface of an inflamed

* Portion of buffy coat of blood, showing fibrous arrangement (rendered more distinct by corrosive sublimate) and colourless corpuscles

† Nucleated blastema.

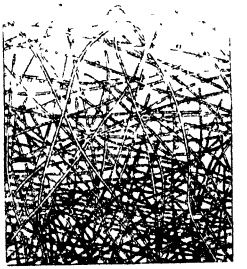
peritoneum. And in Fig. 5 is displayed a similar fibrous structure (in which, however, the fibres have more of a reticulated arrange-

*Fig. 4.**



ment), which incloses the fluid contents of the fowl's egg, and enters into the composition of the shell itself. As the ovum (which, at the time of its quitting the ovarium, consists of the yolk-bag only) passes along the oviduct of the parent, it receives a coating of albuminous matter, of which layer after layer is thrown-out by the vessels of the oviduct. When a sufficient supply has thus been furnished, it appears that fibrinous instead of albuminous matter is poured-forth; and this, in coagulating, forms a very thin layer of fibrous tissue, which envelopes the albumen. Layer after layer is gradually added; and at last, by the superposition of these layers, that firm tenacious membrane is formed, which is afterwards found lining the egg-shell. The process is then continued, with this variation, that carbonate of lime is also secreted from the blood in a chalky state, and its particles lie in the interstices of the fibrous net-work, and give it that solidity which is characteristic of the shell. If they be removed by the

Fig. 5.†



* Fibrous structure of inflammatory exudation from peritoneum.

† Fibrous membrane, lining the Egg-shell, and forming the animal basis of the shell itself.

agency of a weak acid, or if the bird be not sufficiently supplied with lime at the time of laying, the outer membrane has the same consistence as the inner: and either may be separated, after prolonged maceration, by dexterous manipulation, into a series of layers of a fibrous *matting*, like that represented in Fig. 5.

179. It is scarcely possible to deny to such a tissue the designation of an organized structure, even though it contains no vessels, and may not participate in any further Vital phenomena. We shall hereafter find, that a tissue presenting very similar characters forms a large part of the Animal fabric; and that the vessels with which it is copiously supplied, have for their object nothing else than the removal of its disintegrated or decaying portions, and the deposition of new matter in a similar form (§ 194). In the production of new parts, we find this simple fibrous tissue performing the important function of serving as a matrix or bed for the support of the vessels; and as, by the more gradual transformation of the nutritive materials they bring, new and more permanent tissues are formed, the original one gradually undergoes disintegration, and all traces of it are in time lost. This would appear to be the history of the *Chorion* of the Mammalian ovum; which is at first nothing else than a fibrous unvascular bag, formed round the ovum in its passage through the Fallopian tube, precisely after the manner of the shell-membrane of the Bird's egg; but which is afterwards penetrated by vessels proceeding from the embryo, and in time acquires a new structure (CHAP. XI.).

180. The completeness of the production of such a fibrous tissue depends in part, as we have seen, upon the degree of elaboration which the fibrin has undergone; but in great part also upon the nature of the surface on which the coagulation takes place. Thus we never find so perfect a membrane formed by the consolidation of the Fibrin out of the living body,—on a slip of glass for example,—as when it takes-place on the surface of a living membrane, or in the interstices of a living tissue. This may perhaps be accounted for by the fact, that the coagulation takes-place much more slowly in the latter case than in the former, and that the particles may thus have more time to arrange themselves in the definite *fibrillation*, which seems to be their characteristic mode of aggregation: just as *crystallization* takes-place best when the action is slow; and as a substance whose particles would remain in an amorphous or disunited form if too rapidly precipitated from a solution, may present a most regular arrangement when they are separated from it more slowly. Of this view it would seem to be a confirmation, that the most perfect fibrillation out of the body is usually seen in those cases, in which coagulation takes place least rapidly.

181. The conditions under which the spontaneous coagulation of Fibrin takes place, are best known from the observation of that process as it occurs in the Blood; and although this fluid, as we shall

hereafter see, is of a very complex nature, yet as the Fibrin alone is concerned in its coagulation, and as that act would seem to take place in the same manner as if no other substance was present, there appears to be no objection to the employment of the phenomena of Blood-coagulation as the basis of our account of the properties of Fibrin.—There can be no doubt, from Microscopical observation of the circulating Blood, that Fibrin is in a state of perfect *solution* in the fluid; and in this condition it remains, so long as it is in motion in the living body. That its fluidity, however, does not depend only upon its movement, is evident from two facts;—first, that no kind of motion seems effectual in preventing the coagulation of the blood, after it has been drawn from the vessels;—and second, that a state of rest within the living body does not immediately produce coagulation; a portion of blood, included between two ligatures in a living vessel, remaining fluid for a long time; and blood that has been reduced to a state of complete stagnation by inflammatory action, being often found in a fluid state after some days. On the other hand, it seems certain that the state of vitality of the parts with which the blood is in contact, has a great influence in preserving its fluidity; thus it has been found that, if the brain and spinal cord of an animal be broken-down, and by this measure the vitality of the body at large be lowered, clots of blood are formed in their trunks within a few minutes. Nevertheless, a mass of blood effused into any of the principal cavities of the living body, undergoes coagulation almost as soon as it would in a dead vessel; but this may be accounted-for by the very small surface which is in contact with the blood, as compared with the mass of the latter; and when the effusion takes-place into the interstices of the tissues, the blood often preserves its fluidity for many days or even weeks. It must be remembered that the circulating blood is continually being subdivided into countless streams; and that each of these passes through the living tissue, in such a manner that all its particles are in close relation with the living surface. Moreover it is probable that the form of matter which we term Fibrin, never remains long in that condition, in the ordinary state of the system; being continually withdrawn by the nutritive processes, and as continually reformed from the Albumen. Hence we may regard the state of motion through living vessels, as essential to the permanent continuance of fibrin in the fluid form.

182. The length of time, however, during which Fibrin may remain uncoagulated, after it has been withdrawn from the living body, varies according to several conditions; some of which are not well understood. In the first place, as already remarked, the more elaborated and more concentrated the condition of the Fibrin, the more slowly does it usually coagulate. Thus when a large quantity of blood is drawn at one bleeding, into several vessels, that which flows first takes the longest time to coagulate, and forms the firmest

clot; whilst that which is last drawn coagulates most rapidly and with the least tenacity. The coagulation is accelerated by moderate heat, and retarded by cold; but it is not prevented even by extreme cold; for if blood be frozen immediately that it is drawn, it will coagulate on being thawed,—thus preserving its vitality, in spite of the freezing process, like the organized structures of many of the lower animals. Again, the coagulation is accelerated by exposure to air; but it is not prevented, though it is retarded, by complete exclusion from it. Various Chemical agents retard the coagulation, without preventing it; this is the case especially with solutions of the neutral salts. The coagulation is not so firm, however, or the fibrillation so perfect, after the use of these; and there can be no doubt that they modify the properties of the fibrin, by acting chemically upon it.

183. After remaining in this condition for a certain length of time, the Fibrin undergoes a further change, which is evidently the result of decomposition; the coagulum becomes soft, and exhibits appearances of putrefaction. This takes place the more rapidly, as the first coagulation was less complete. Thus in the imperfectly-elaborated Fibrin of the Chyle, the coagulum is sometimes so incomplete, that it does not separate itself from the serum, and liquefies again in half an hour. In certain states of disease, the solidifying properties of the Fibrin are very much impaired, so that it soon liquefies and decomposes: and in these cases, there is scarcely any trace of the characteristic fibrous arrangement of the particles.—On the other hand, the fibrinous coagulum of inflamed blood, as it is more solid, is also more persistent, than that of ordinary blood; and the greatest persistency of all is seen in the fibrous network formed by exudation, as in the cases just now mentioned.

184. The coagulating power of Fibrin,—in other words, its peculiar vital property,—may be destroyed by various causes operating within the living body; so that the blood remains fluid after death. These may be classed under three heads. In the first place, the vitality of the fibrin may be destroyed by substances introduced into the blood from without; which have the power of acting in the manner of *ferments*, and which occasion an obvious chemical change in its condition. Such is the case in those severe forms of Fever which are termed *malignant;* and especially those which result from the contact of putrescent matter, as Glanders, Pustule maligne, &c. Secondly, it may be impaired or altogether destroyed by morbid actions originating in the system itself, and depending upon irregular nutrition or imperfect excretion; thus the blood has been found fluid after death in severe cases of Scurvy and Purpura, also in cases of Asphyxia (consequent upon the retention of carbonic acid in the blood), and in the bodies of over-driven animals. The same result may follow, Thirdly, from

violent shocks or impressions, which suddenly destroy the vitality of the whole system at once; these may be such as are obviously capable of producing a chemical or mechanical change, as in the case of death by Lightning or by a violent Electrical discharge; or they may act through the nervous system, in a manner not yet clearly understood, as when death results from concussion of the brain, from a blow upon the epigastrium, from violent mental emotion, or from a coup de soleil.—It is not to be supposed that the non-coagulability of the Blood is a phenomenon by any means invariable under the foregoing circumstances; but it has been occasionally observed in all of them. We must not mistake for the *absence of coagulating power*, the remarkable *retardation of the act of coagulation* which sometimes occurs. Thus, the blood is occasionally found in a fluid condition in the bodies of persons that have been dead for some days; and yet, when withdrawn from the vessels, it coagulates.

185. Although the tissues most actively concerned in carrying-on the *vital* operations, seem to have a composition essentially Albuminoid, yet that very large proportion of the fabric of the higher animals, whose offices are essentially *mechanical*, has for its organic basis compounds of a very different nature, of which *Gelatin* may be taken as the type.—This substance is obtained by the action of boiling water on White Fibrous tissue, and on the various membranes, &c., of which this tissue is the chief component. The composition of Gelatin is much simpler than that of the Protein-compounds, so far, at least, as regards the number of atoms of its several elements; for it consists of 13 Carbon, 10 Hydrogen, 5 Oxygen, 2 Nitrogen. This composition is the same, whether the Gelatin be obtained from isinglass, from fibrous membranes, or from bones. The distinctive characters of Gelatin are its solubility in warm water, its coagulation on cooling into a uniform jelly, and its formation of a peculiar insoluble compound with Tannic acid. Gelatin is very sparingly soluble in cold water; though prolonged contact with it will cause the Gelatin to swell-up and soften. Its power of forming a jelly on cooling is such, that a solution of one part in 100 of water will become a consistent solid. And its reaction with Tannic acid is so distinct, that the presence of one part of Gelatin in 5000 of water is at once detected by infusion of Galls.—There can be no doubt that Gelatin does not exist *exactly as such* in the Fibrous tissues; since none can be dissolved out of them by the continued action of cold water, and it usually requires the *prolonged* action of hot water, to occasion their complete conversion. There are some substances, however, in which this is not requisite, and from which the gelatin may be extracted within a shorter time: this is the case, for example, with the air-bladder of the Cod and other fish, which, when cut into shreds and dried, is known as Isinglass; it is the case also with the substance of bones, from

which the calcareous matter has been removed. In both instances it would seem that the state of organization is very imperfect; the fibrous structure being by no means well-marked. When the fibrous arrangement is more complete, the solubility of the tissue is much diminished; and hence it would seem that the particles have a different arrangement in the tissues, from that which they have in the product obtained by boiling. Their ultimate composition, however, is the same; for when any serous membrane, or other tissue principally composed of the white fibrous element, is analysed by combustion, the elements are found to have the same proportion to each other as in Gelatin, allowance being made for the small admixture of other substances. The action of Tannic acid, too, is the same on the organized tissue, as it is on the gelatin extracted from it; and hence results its utility in producing an insoluble compound, not liable to undergo decomposition, in the substance of the Skin, converting it into leather.

186. A peculiar modification of Gelatin, which presents itself in Cartilage, is distinguished as *Chondrin*. This requires longer boiling than gelatin, for its solution in water; but the solution fixes into a jelly in cooling, and dries by evaporation into a glue that cannot be distinguished from that of gelatin. Like gelatin, it is thrown down from its solution by alcohol, creosote, tannic acid, and bichloride of mercury; but it is also precipitated by the hydrochloric and acetic acids, alum, acetate of lead, and protosulphate of iron, which do not disturb a solution of gelatin.—It is curious that, in proportion as Cartilages become *fibrous*, their Chondrin gives place to Gelatin; and during the progress of ossification, the Chondrin seems to be entirely replaced by Gelatin, of which the fibrous basis of the bony tissue is composed. From this and other considerations, it seems likely that Chondrin stands as an intermediate term between the Albuminoid compounds and Gelatin proper.

187. It is not yet known how the Gelatinous Compounds are produced in the Animal body. There can be no doubt that they may be elaborated from Albumen; since we find a very large amount of Gelatin in the tissues of young animals, which are entirely formed from albuminous matter; and also in the tissues of herbivorous animals, which cannot receive it in their food, as Plants yield no substance resembling gelatin. And although Carnivorous animals will receive it ready formed as part of their aliment, yet there is very strong reason to believe that it does not serve even for the nutrition of the gelatinous tissues, which seem all to be formed at the expense of the plasma of the blood. It may be considered as certain that it is incapable of being converted into Albumen; and consequently that it can never be applied to the nutrition of the albuminous tissues (§ 429).—If Gelatin be boiled for some time in caustic potash, it is decomposed, with an escape of ammonia; and two new compounds, *leucine*, and *glycine* or gelatine-sugar, are

generated. The production of leucine from Gelatin, by the action of the same reagent as that which caused its generation from Albumen, is a fact of much importance; as showing that, notwithstanding their difference of composition and characters, a certain similarity in the arrangement of their ultimate elements still subsists between these two bodies. Glycine is an organic base of great interest from its relations to other substances; as will be shown hereafter. It has a strong sweet taste, and is very soluble in water, from which it may be crystallized like ordinary sugar. Its composition is comparatively simple; being 4 Carbon, 4 Hydrogen, 1 Nitrogen, 3 Oxygen.

2. *Of the Simple Fibrous Tissues.*

188. A large part of the Animal fabric, especially among the higher classes in which the parts have the greatest amount of motion upon one another, is composed of tissues, which seem as if they consisted of nothing else than *fibres*, of the simple character already described, woven together in various ways, according to the purposes they are destined to serve. These fibres are altogether different from those hereafter to be described as constituting the Muscular and Nervous tissues, and must not be confounded with them. The former are *solid*, and possess none but *physical* properties; the latter are *tubular*, and are distinguished by their peculiar *vital* endowments, which seem chiefly, if not entirely, to reside in the *contents* of the tubular fibre. The Simple Fibrous tissues, of which we have now to treat, appear to have it for their sole office in the animal body, to bind-together the other component parts into one whole, without uniting them so closely as to render them immoveable; and we find the same elements arranged in very different modes, according to the purposes they are destined to fulfil. Thus in the *Tendons*, by which the muscles are connected with the bones, and impart motion to them, the only property required is that of resisting strain or tension in *one* direction; and in these we find the fibres disposed in a parallel arrangement, passing continuously in straight line between the points of attachment. In the *Ligaments* which connect the bones together, and which also have for their purpose to afford resistance to strain, but which are liable to tension in a greater variety of directions, we find bundles of fibres crossing each other according to these directions; and in some instances we find the ligaments endowed also with a certain degree of elasticity. The structure of the strong *Fibrous Membranes*, which form the envelopes to different organs and bind together the contained parts, is very similar; each of these membranes being composed of several layers of a dense network, formed by the interweaving of bundles of fibres in different directions. In the *Fibro-Cartilages*, we find a mixture of the characteristic structure

of Ligament with that of Cartilage; bundles of fibres, similar to those which constitute the former, being disposed among the cells which are the chief organized constituents of the latter. In certain Fibro-Cartilages, moreover, these fibres are endowed with a high degree of elasticity.

189. These two qualities,—that of resistance to tension without any yielding,—and that of resistance combined with elasticity,—are characteristic of two distinct forms of Fibrous tissue, the *White* and the *Yellow*. The *White Fibrous* tissue presents itself under various forms, being sometimes composed of fibres so minute as to be scarcely distinguishable; but more generally presenting itself under the aspect of bands, usually of a flattened form and somewhat wavy in their direction, and attaining the breadth of 1-500th of an inch (Fig. 6). These bands are marked by numerous longitudinal streaks, but they cannot be torn-up into minute fibres of determinate size; hence they must be regarded as made-up of an aggregation of the same elements as those which may become developed into separate fibres. This tissue, which is perfectly inelastic, is easily distinguished from the other by the effect of Acetic acid, which swells it up, and renders it transparent, at the same time bringing into view certain oval corpuscles, which are supposed to be the nuclei of the cells that were concerned in its formation.

Fig. 6.*



190. The *Yellow Fibrous* tissue exists in the form of long, single, elastic, branched filaments, with a dark, decided border: which are disposed to curl when not put on the stretch (Fig. 7). They are for the most part between 1-5000th and 1-10,000th of an inch in diameter; but they are often met-with both larger and smaller. They frequently anastomose, so as to form a network, as shown in Fig. 6; this condition especially prevails in the middle coat of the arteries. The yellow fibrous tissue does not undergo any change, when treated with acetic acid. It exists alone (that is, without any mixture of the white) in parts which require a peculiar elasticity, such as the middle coat of the Arteries, the Chordæ Vocales, the Ligamentum Nuchæ (of Quadrupeds), and the

* White or Non-elastic Fibrous tissue.

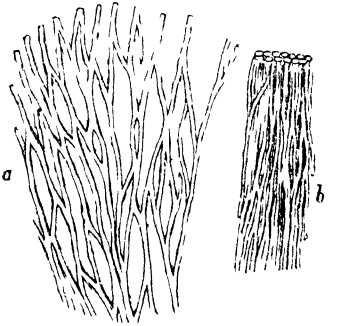
Ligamenta subflava; it enters largely into the composition of certain parts, which are commonly regarded as cartilaginous, such

*Fig. 7.**



as the External Ear; and it is also a principal component of other tissues to be presently described.

Fig. 8.†



191. The foregoing tissues are very different in Chemical composition. Those which are composed of the *White* fibrous element, —namely, Tendons, Ligaments, &c.—are almost entirely resolved by long boiling into *Gelatin;* and this substance is also largely obtained from the Skin, and from Mucous and Serous membranes, of which, as we shall presently see, that element is a principal

* Yellow or Elastic Fibrous tissue, from ligamentum nuchæ.

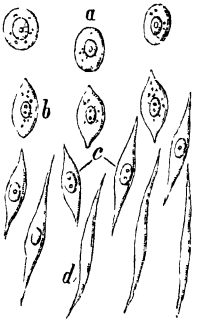
† Anastomosing form of Yellow Fibrous tissue; *a*, the fibres drawn apart to show their reticulate arrangement; *b*, the fibres *in situ*.

component; whilst it is also yielded in great quantity by Bones, whose animal basis is almost entirely gelatinous.

192. The composition of the *Yellow* fibrous tissue appears to be altogether dissimilar. It scarcely undergoes any change by prolonged boiling; it is unaffected also by the weaker acids; and it preserves its elasticity, if kept moist, for an almost unlimited period. According to Scherer, it consists of 48 Carbon, 38 Hydrogen, 6 Nitrogen, and 16 Oxygen; and he considers it to be composed of an atom of Protein with two atoms of water.

193. The simple Fibrous tissues appear to be very little susceptible of change in the living body; and we find them very sparingly supplied with blood-vessels. In the solid Tendons, the bundles of straight parallel fibres are a little separated from each other by the intervention of the Areolar tissue to be presently noticed; and this permits the sparing access of vessels to their interior. In the Fibrous Membranes and Ligaments, this is found in somewhat larger amount; and the vascularity of these tissues is rather greater.—Two different views of their mode of development have been taken by those who have studied it. By some it has been maintained that the White fibres are first developed as cells, which progressively become elongated and solidified (Fig. 9), their nuclei at the same time disappearing, until brought into view by acetic acid; and the Yellow fibres have been supposed to have a similar origin. By others it has been considered that the White fibres are produced by the direct fibrillation of a *blastema* or plastic exudation (§ 178), and that the Yellow proceed from the nuclear particles which this contains; no development of cells being requisite for the production of either. The recent inquiries of Mr. Paget and others tend to show that *both* these methods are adopted in the production of the fibrous tissue which is developed for the repair of injuries in the adult body; the former being seen in the reparation of external wounds to which air has access; the latter in the organization of 'coagulable lymph' effused into internal cavities, or into the interstices of tissue, altogether secluded from it.

Fig. 9.*



* Development of Fibres from Granulation-cells:—*a*, circular or oval nucleated cells; *b*, the same becoming pointed; *c*, the same become fusiform, the nuclei being still apparent; *d*, the same elongating into fibres, the nuclei having disappeared.

194. The great use of the foregoing Tissues appears to be, to afford a firm resistance to tension; by which they may either communicate motion, as in the case of Tendons; or restrain it, as in the case of Ligaments; or altogether prevent it, as in the case of Aponeuroses and Fibrous Membranes. With this firm resistance, a considerable amount of elasticity may be combined.—But we have now to notice a tissue, in which a very different arrangement of the same elements presents itself; and the object of this is to bind together the elements of the different fabrics of the body, and at the same time to endow them with a greater or less degree of freedom of movement one upon another. This tissue, which is called the *Areolar*, consists of a network of minute fibres and bands, which are interwoven in every direction, so as to leave innumerable *areolæ* or little spaces, which communicate freely with each other. Of these fibres, some are of the yellow or elastic kind; but the majority are composed of the white fibrous tissue, and, as in that form of elementary structure, they frequently present the form of broad flattened bands, or membranous shreds, in which no distinct fibrous arrangement is visible (Fig. 10). The interstices are filled during life with a fluid, which resembles very dilute serum of the blood; consisting chiefly of water, but containing a sensible quantity of common salt and albumen. This tissue (which has been frequently but erroneously termed Cellular) is very extensible in all directions, and very elastic, from the structural arrangement of its elements. It cannot be said to possess any distinctly *vital* endowments; for although it has a certain amount of *sensibility*, this merely depends upon the presence of nerves which it is conveying to other parts; and the small amount of *contractility* which it shows, depends rather upon the muscular tissue of the vessels that traverse it.

Fig. 10.*



195. As already mentioned, we find this tissue in almost every part of the body; thus it binds together the ultimate fibres of the Muscles into minute fasciculi, unites these fasciculi into larger ones,

* Portion of Areolar tissue, showing it to be composed of bands of White fibrous tissue, and of isolated Yellow fibres.

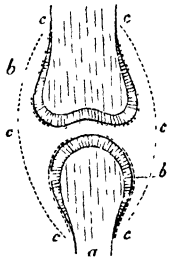
these again into larger ones which are obvious to the eye, and these into the entire muscle. Again, it forms the membranous septa between distinct muscles, or between muscles and fibrous aponeuroses. In like manner it unites the elements of nerves, glands, &c.; binds together the fat-cells into minute bags, these into larger ones, and so on; and in this manner penetrates and forms a considerable part of all the softer tissues of the body. But it is a great mistake to assert, as it was formerly common to do, that it penetrates the harder organs, such as bones, teeth, cartilage, &c. Its purpose obviously is, to allow a certain degree of movement of the parts which it unites; and hence we find it entering much more largely into the composition of the Mammary gland (which, from its attachment to the great pectoral muscle, must have its parts capable of being shifted upon one another), than into that of the Liver, Kidneys, &c. It also serves as the *bed* in which blood-vessels, nerves, and lymphatics may be carried into the substance of the different organs; and it often undergoes a degree of condensation, in order to form a sheath for the larger trunks, which gives it almost the characters of a Fibrous Membrane.

196. The quantity of fluid in the interstices of Areolar tissue is subject to considerable variations; but these depend rather upon the state of fulness or emptiness of the vessels which traverse it, and upon the condition of the walls of those vessels, than upon any change in the tissue itself. It has been shown that when an albuminous fluid is in contact with an animal membrane, the watery part of the fluid will pass through by transudation; but that the albuminous matter will be for the most part kept back, so that only a very small proportion of it is to be found in the transuded liquid. This appears to be a sufficient explanation of the presence of a weak serous fluid in the cavities of areolar tissue; and there is not any necessity, therefore, to imagine the existence of a secreting power, either in the areolar tissue itself, or in the walls of the capillaries which traverse it. When there is a want of firmness or tone in the walls of the vessels, producing (as we shall hereafter see, § 609) an increased pressure of the contained fluid on their walls, and diminished resistance, the watery part of the blood will have an unusual tendency to transudation: and we accordingly find that it then distends the areolæ, and produces *dropsy*. The physical arrangement of the parts of the tissue is so much altered, that its elasticity is impaired; and it consequently *pits* on pressure,—that is, when pressure has made an indentation in the surface, this is not immediately filled-up when the pressure is withdrawn, but a *pit* remains for some seconds or even minutes. The free communication which exists among the interstices, is shown by the influence of gravity upon the seat of the dropsical effusion; this always having the greatest tendency to manifest itself in the most depending parts,—a result, however, which is also due to the increased delay that

takes place in the circulation in such parts, when the vessels are deficient in tone. This freedom of communication is still more shown, however, by the fact, that either air or water may be made to pass, by a moderate continued pressure, into almost every part of the body containing Areolar tissue; although introduced at only a single point. In this manner it is the habit of butchers to *inflate* veal; and impostors have thus *blown-up* the scalps and faces of their children, in order to excite commiseration. The whole body has been thus distended with air by emphysema in the lung; the air having escaped from the air-cells into the surrounding areolar tissue, and thence, by continuity of this tissue with that of the body in general at the root or apex of the lungs, into the entire fabric.

197. The structure of the *Serous* and *Synovial* Membranes is essentially the same with that of Areolar tissue. It is the peculiar character of these membranes to form *closed* bags or sacs, having a very smooth and glistening inner surface, and containing a fluid more or less allied in composition to the serum of the blood. The disposition of the *Synovial* membranes may be understood by studying one of the simpler forms of the joints, such as is represented in the accompanying diagram; but although *originally* continuous over the surfaces of the Articular Cartilages, the Synovial membrane does not continue to be distinctly traceable after the joint has come into play; and its vessels, retreating from the portion over which the two surfaces are exposed to friction, form a circle round its margin, from which the Cartilage is nourished (§ 278).—The arrangement of the *Serous* membranes is usually much more complicated. These line the three great cavities of the body, the Head, Chest, and Abdomen, together with their subdivisions; enveloping the viscera which these contain, so as to afford them an external coating over every part save that by which they are suspended; and being then reflected over the interior of the cavity, so as to form a shut sac intervening between its outer walls and its contents. The chief purpose of this appears to be, to facilitate the movements of the contained organs, by forming smooth surfaces which shall freely glide over each other; this is evidently of great importance where such constantly-moving organs as the heart and lungs are concerned.

Fig. 11.*



198. The free or unattached surface of these membranes is

* Ideal section of a Joint:—*a*, *a*, the extremities of the two articulated bones; *b*, *b*, the layers of cartilage which cover them; *c*, *c*, *c*, *c*, synovial membrane covering the articular surfaces, and passing from one to the other.

covered with a layer of cells; but these constitute a distinct tissue, the *Epithelium*, of which an account will be given hereafter (§ 231). The epithelium lies upon a continuous sheet of membrane, of extreme delicacy, in which no definite structure can be discovered; the nature of this, which is called the *basement-membrane*, will be presently considered (§ 206). Beneath this is a layer of condensed Areolar tissue, which constitutes the chief thickness of the serous membrane, and confers upon it its strength and elasticity; this gradually passes into that laxer variety, by which the membrane is attached to the parts it lines, and which is commonly known as the *sub-serous* tissue. The yellow fibrous element enters largely into the composition of the membrane itself; and its filaments interlace in a beautiful net-work, which confers upon it equal elasticity in every direction. The membrane is traversed by blood-vessels, nerves, and lymphatics, in varying proportions; and some of the synovial membranes, especially that of the knee-joint, are furnished with little fringe-like projections, which are extremely vascular, and which seem especially concerned in the secretion of the synovial fluid. The fluid of the serous cavities is so nearly the same as the serum of the blood, that the simple act of transudation is sufficient to account for its presence in their sacs; on the other hand, that of the Synovial capsules, and of the Bursæ Mucosæ which resemble them, may be considered as serum with from 6 to 8 per cent. of additional albumen.

199. The elements of Areolar tissue enter largely also into two other textures, which perform a most important share in both the Organic and the Animal functions;—namely, the *Mucous Membranes* and the *Skin*. These textures are continuous with each other; and may, in fact, be considered as one and the same, modified in its different parts according to the function it is destined to perform. Thus it is everywhere extremely vascular; but the supply of blood in the Skin is chiefly destined for the nervous system, and is necessary to the act of sensation; whilst that of the internal skin or Mucous Membrane is rather subservient to the processes of absorption and secretion. This tissue is continued inwards from the external surface of the body, by the several orifices and outlets of its cavities; and it is further continued most extensively from its primary internal prolongations, into the inmost recesses of the glandular structures.

200. Thus the *Gastro-intestinal* mucous membrane commences at the mouth, and lines the whole alimentary canal from the mouth to the anus, where it again becomes continuous with the skin; and it sends off, as branches, the membranous linings of the ducts of the salivary glands, pancreas, and liver; these membranes proceed into all the subdivisions of the ducts, and line the ultimate follicles or cæca in which they terminate. Again, the *Bronchio-pulmonary* mucous membrane commences at the nose, and passes along the air-

passages, down the trachea, through the bronchi and their subdivisions, to line the ultimate air-cells of the lungs; communicating in its course with the gastro-intestinal. Another mucous membrane of small extent commences at the puncta lachrymalia, lines the lachrymal sac and the nasal duct, and becomes continuous with the preceding. Another, which may be considered a kind of offset from either of the first two, passes up from the pharynx along the Eustachian tube, and lines the cavity of the tympanum.

201. Near the opposite termination of the alimentary canal, moreover, we have the *Genito-urinary* mucous membranes, which commence in the male by a single external orifice, that of the urethra:—passing backwards along the urethra, the *genital* division is given off, to line the seminal ducts, the vesiculæ seminales, the vasa deferentia, and the secreting tubuli of the testis; another division proceeds along the ducts of the prostate gland, to line its ultimate follicles, and another along the ducts of Cowper's glands:—whilst the *urinary* division lines the bladder, passes-up along the ureters to the kidney, and then becomes continuous with the membrane of the tubuli uriniferi. In the female, the urinary division commences at once from the vulva; whilst the genital passes along the vagina into the uterus, and thence along the Fallopian tubes to their fimbriated extremities, where it becomes continuous with the serous lining of the abdominal cavity, the peritoneum.

202. Besides the glandular prolongations here enumerated, there are many others, both from the internal and external surface. Thus we have the *Mammary* mucous membrane, commencing from the orifices of the lactiferous ducts, passing inwards to line their subdivisions, and forming the walls of the ultimate follicles. In the same manner, the *Lachrymal* mucous membrane is prolonged from the conjunctival mucous membrane, which covers the eye and lines the eyelids, and which is continuous with the skin at their edges.—There are several minute glands, again, in the substance of the skin, and in the walls of the alimentary canal, which need not be here enumerated; but which contribute immensely to the extension of the surface of the mucous membrane, a prolongation of this being the essential constituent in every one. In their simplest form, these glandulæ are nothing more than little pits or depressions of the surface; these are found both in the Skin and Mucous membrane, and are particularly destined for the production of their protective secretions, hereafter to be described.

203. We have seen, then, that the essential character of the Mucous membranes, as regards their arrangement, is altogether different from that of the serous and synovial membranes. For whilst the latter form shut sacs, the contents of which are destined to undergo little change, the former constitute the walls of tubes or cavities, in which constant change is taking-place, and which have free outward communications. Thus in the Gastro-intestinal mucous

membrane, we have an inlet for the reception of the food, and a cavity for its solution, the walls of which are endowed in a remarkable degree with absorbing power, in virtue of the outward extension of their surface by villous prolongations (Fig. 28, *a*); whilst they are also furnished with numerous glandulæ, formed by inflexions of their surface (*b*), which pour the solvent fluid into the cavity. On the other hand, it has an outlet, through which the indigestible residuum is cast-forth, together with the excretions from the various glands that pour their products into the alimentary tube. In the Bronchio-pulmonary apparatus, the same outlet serves for the introduction and for the expulsion of the air; and here, too, is continual change. In other cases, in which there is but a single outlet, the change is of a simpler character, consisting merely in the expulsion of the matters eliminated from the blood by the agency of the glands. Now it is, as we shall see hereafter, in the digestion and absorption of food, on the one hand, and in the rejection of effete matters on the other, that the commencement and termination of the nutrient processes consist; and these operations are performed by the system of Mucous membranes, including in that general term the Skin, which is an important organ of excretion, besides serving as the medium through which sensory impressions of a *general* character are received by the Nervous system.

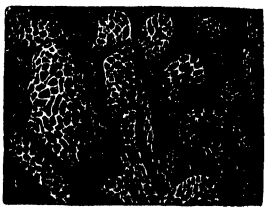
204. The *Skin* or *Mucous Membrane* may be said, like serous membrane, to consist of three chief parts;—the epithelium or epidermis covering its free surface;—the subjacent basement-membrane;—and the areolar tissue, with its vessels, nerves, &c., which forms the thickness of the membrane, and connects it with the subjacent parts. The Epidermis and Epithelium alike consist of cells; but the function of the former (which consists of several layers, of which the outer are dry and horny) is simply protection to the delicate organs beneath; whilst that of the latter is essentially connected with the process of Secretion, as will be shown hereafter. The basement-membrane resembles that of the serous membranes; but its separate existence is unusually evident in some parts where it exists alone, as in the tubuli uriniferi of the kidney; whilst it can with difficulty be demonstrated in others, as the skin. The Areolar tissue of Mucous membranes usually makes-up the greatest part of their thickness; and it is so distinct from that of the layers beneath, constituting the sub-mucous tissue, as to be readily separable from them. It differs not in any important particular, however, from the same tissue elsewhere; and the white and fibrous elements may be detected in it in varying proportions, in different parts,—the latter being especially abundant in the skin and lungs, which owe to it their peculiar elasticity. Hence the Skin and Mucous membranes yield Gelatine in abundance, on being boiled. The skin also appears to contain some of the non-striated Muscular fibre (§ 337), in varying proportions in its different parts.

205. The relative amount of Blood-vessels, Nerves, and Lymphatics, as already mentioned, is subject to great variation, according to the part of the system examined. The first, however, are most constantly abundant, being required in the Skin (Fig. 12) for

Fig. 12.*



Fig. 13.†



sensation and for the production of epidermis, and in the Mucous membranes (Figs. 13, 14, 15) for absorption and secretion. In fact

Fig. 14.‡

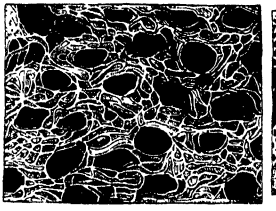
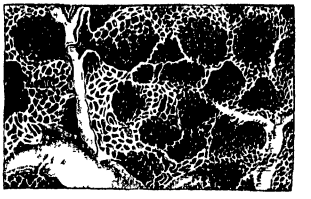


Fig. 15 §

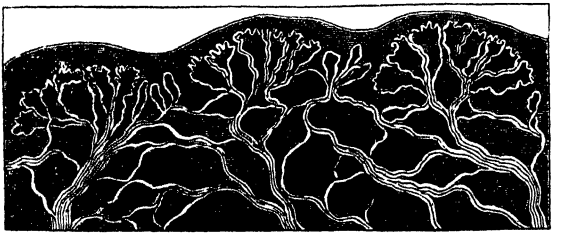


we might say of many of the mucous membranes, especially those of the glands, that their whole purpose is to give support to the secreting cells, and to convey blood-vessels into their immediate neighbourhood, whence these cells may obtain materials for their development. The Skin is the only part of the whole system which is largely supplied with Nerves (Fig. 16), except the Conjunctival membrane and the Mucous membrane of the mouth and nose; hence the sensibility of the internal mucous membrane is usually low, although its importance in the organic functions is so great. The Skin is copiously supplied with Lymphatics, as is the mucous membrane of the first part of the alimentary canal with Lacteals;

* Distribution of Capillaries at the surface of the Skin of the finger.
† Distribution of Capillaries in the Villi of the Intestine.
‡ Distribution of Capillaries around follicles of Mucous Membrane.
§ Distribution of Capillaries around the follicles of Parotid Gland.

some of the glandular organs are also largely supplied with Lymphatics.—The Areolar tissue, whether existing separately, or

Fig. 16.*



forming a part of the Serous and Mucous Membranes, is capable of being very quickly and completely regenerated; indeed, we often find that losses of substance in other tissues are replaced by means of it.

3. *Of the Basement-Membrane.*

206. In many parts of the Animal body, we meet with membranous expansions of extreme delicacy and transparency, in which no definite structure can be discovered; and these seem, like the simple fibres already described, to have been formed, rather *directly* from the nutritive fluid, than indirectly by any previous process of transformation. Hence we may regard such membranes and fibres as constituting the most simple or elementary forms of Animal tissue. The characters of membranes of this kind were first pointed out by Mr. Bowman and Prof. Goodsir; by the former of whom it was termed *basement*-membrane, as being the foundation or resting-place for the epithelium-cells which cover its free surface (§ 231); whilst by the latter it was termed the *primary* membrane, as furnishing the germs of those cells. As, however, this last idea is hypothetical, and is not borne-out by the results of more recent observations, the term basement-membrane, which simply expresses the fact of position, seems decidedly preferable.—In its very simplest form, the basement-membrane is a pellicle of such extreme delicacy, that its thickness scarcely admits of being measured; it is to all appearance perfectly homogeneous, and presents not the slightest trace of structure under the highest powers of the microscope, appearing like a thin film of coagulated gelatine. Examples of this kind may be easily procured, by acting upon the inner layer

* Distribution of the tactile Nerves, as seen in a thin perpendicular section of the Skin at the extremity of the human thumb.

of any bivalve shell with dilute acid; this dissolves-away the calcareous matter, and leaves the basement-membrane. In other cases, however, the membrane is not so homogeneous; a number of minute granules being scattered, with more or less of uniformity, through the transparent substance. And we occasionally find a faintly-indicated areolation, which seems to indicate a disposition in the homogeneous membrane to resolve itself into distinct cells.—Hence it would seem as if the first and simplest form were produced by the simple consolidation of a thin layer of homogeneous blastema; the second, by a layer of such blastema, including nuclear granules; and the third, by the incipient *cellulation* of this blastema,—a process analogous to the *fibrillation* which takes-place under other circumstances (§ 178). We find the basement-membrane, under one or other of these forms, on *all* the free surfaces of the body, beneath the epithelial or epidermic cells. Thus, as already mentioned, it constitutes the outer layer of the true Skin; it lines all the cavities formed by Mucous membranes, and is prolonged into all the ducts and ultimate follicles and tubuli of the Glands which are connected with them (§ 199); indeed it may be said in many instances to be the sole constituent of the walls of these follicles and tubuli, the subjacent tissue not being continued to their finest ramifications. Again, it forms the innermost layer of the Serous and Synovial membranes; and it also lines the blood-vessels and lymphatics, forming the sole constituent of the walls of *their* minutest divisions.

207. In every one of these cases, we find the *free* aspect of the Basement-Membrane in contact with *cells*, which form a more or less continuous layer upon its surface. These cells can only receive their nutriment by the imbibition of fluid, through the basement-membrane, from the blood brought to its attached surface by the capillary vessels of the tissue with which it is in relation. Thus in the Skin and Mucous membranes, a very copious supply of blood is brought to the attached surface of the basement-membrane, by the minutely-distributed capillaries which form a large part of the subjacent tissue; and it is through it, that the epidermis and epithelium draw their nourishment from these. In like manner, the ultimate follicles and tubuli of the Glands are surrounded by a copious network of capillaries (Fig. 15); and it is from these, through the basement-membrane, that the cells of these follicles derive the materials of their growth. Hence this membrane, in every instance, forms a complete septum, on the one hand between the stream of blood in the vessels and the surrounding tissues, since it forms the lining even of the minutest capillaries; and on the other between the fluids in the interstices of the substance of the true skin, the mucous membranes, &c., and the cells covering their free surfaces. It is evident, therefore, that whilst bounding these tissues and restraining the too-free passage of fluids from their surfaces, it

allows the transudation of a sufficient amount for the nutrition of the cells which lie upon it; and, as we shall presently see, these cells frequently pass through all their stages of growth so rapidly, that a very copious supply of nutriment must be required by them. Hence, notwithstanding its apparent homogeneousness, the primary membrane must have a structure which readily admits the passage of fluid. In this respect it corresponds with the membrane which forms the wall of the *cells* of both Animal and Vegetable tissues; for this also appears completely homogeneous and structureless, when seen under its simplest aspect, and yet allows the free passage of fluids from one cell to another.

4. *Of Simple Isolated Cells, employed in the Organic Functions.*

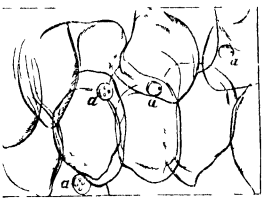
208. The active functions of the Animal body are performed, to a much greater extent than was formerly believed, by the agency of *simple isolated cells;* of which every one grows and lives quite independently of the rest, just as if it were one of the simplest Cellular Plants (§ 21); but of which all are dependent upon the general nutritive fluid for the materials of their development, imbibing it from the currents that circulate in their neighbourhood. It may be said, indeed, that *all* the Vegetative functions of the body,—all the processes of Nutrition and Reproduction,—all those operations, in short, which are common to Plants and Animals,—are performed in the Animal and Vegetable structures by the very same means, the agency of cells; and this is true, not only of the healthy actions, but of various morbid operations, in which the unusual development of cells, possessing peculiar endowments, performs a most conspicuous part. Hence it will be necessary to enter somewhat at large into the history of cell-development in the Animal body, and the various modifications under which this process may take place. In fact, a knowledge of the Physiology of Cells may be regarded as the foundation of all accurate acquaintance with that department of the Science which relates to the Nutritive and Reproductive processes; and it has a considerable bearing, as we shall see hereafter, upon the history of the purely Animal functions.

209. The history of the Animal cell, in its simplest form, is essentially that of the Vegetable cell of the lowest kind (§§ 21, 22); excepting in so far as it is dependent for its nutriment upon organic compounds previously elaborated, instead of generating these for itself. It lives *for* itself and *by* itself; and is dependent upon nothing but a due supply of nutriment and of the appropriate stimuli, for the continuance of its growth and for the due performance of all its functions, until its term of life be expired. In whatever method it originates (and we shall presently see that the life of an independent cell may commence in various modes), it

attracts to itself, assimilates, and organizes, the particles of the nutrient fluid in its neighbourhood; it converts some of them into the substance of its cell-wall, whilst it draws others into its cavity; in this manner it gradually increases in size; and whilst it is itself approaching the term of its life, it may make preparation for its renewal, by the development of reproductive particles in its interior, which may become the germs of new cells, when set-free from the cavity of the parent. So far as is yet known, the composition of the *cell-wall* is everywhere essentially the same, being uniformly Albuminoid. It is in the nature of the *contents* of the cell, that (as among the cells of Plants) the greatest diversity exists; and we shall find that the *purposes* of the different groups of cells, in the Animal economy, depend upon the nature of the products they secrete, and upon the mode in which these products are given-back, after they have been subjected to the action of the cells.

210. In the interior of most Animal cells, usually attached to some part of their wall, but sometimes lying free within their cavity, there may be seen a peculiar body, ordinarily of round or oval shape, which is called the *nucleus* (Fig. 17, *a*). The size of this body is more constant than that of the cell itself, being usually between 1-6000th and 1-4000th of an inch. Its aspect, however, varies greatly; for it sometimes appears quite solid, as if made up of an aggregation of granules; in other instances it seems to be of less consistence towards the centre than it is on the surface; whilst not unfrequently, as if by a further advance in this kind of differentiation, it presents a vesicular aspect, having a consistent membrane externally, which encloses a cavity within. When this is the case, the nuclear vesicle is usually seen to contain one or more aggregations of minute granules, apparently of fatty matter, which are termed *nucleoli*. The chemical composition of the nucleus differs from that of the cell-wall; for whilst the latter is dissolved by acetic acid, the former (like the yellow or elastic tissue, with which its substance appears to have some relationship) is unchanged by it; and acetic acid thus becomes a very useful reagent for bringing nuclear bodies into strong relief, whether they are contained within cells, or are imbedded in the midst of simple fibres (§ 193), or are attached to the walls of tubes, such as the membrane of capillary

Fig. 17.*



* Cells from Chorda Dorsalis of Lamprey;—*a*, *a*, their nuclei.

blood-vessels, or the sarcolemma of muscular fibre.—The nucleus appears to be the centre of the vital forces of the cell; being the part through which it specially exerts its agency on the substances brought under its influence; and being also the chief instrument in the reproductive operation There is reason to believe, indeed, that nuclear bodies may exert their vital power, and may effect the transformation or new arrangement of organic compounds, without the formation of a cell-membrane, the purpose of the latter, indeed, being apparently to bound or limit the substances drawn together by the nucleus, and to cut them off from others in their neighbourhood. When the formation of a cell is complete, and it is not destined to reproduce its kind, the nucleus frequently disappears, this is the case, for example, with the Red corpuscles of the Blood of Mammalia (§ 215), and also with Fat-cells (§ 257).

211. New cells may originate in one of two principal modes, either directly from a pre-existing cell, or by an entirely-new production in the midst of an organizable blastema —The development of new cells from a pre existing cell, again, may take-place in one of two modes, either by the binary subdivision of the parent-cell, or by the production of a number of new cells in its interior; the *nucleus*, in each case, appearing to perform an important part in the process Of the multiplication of cells by subdivision, we have a characteristic

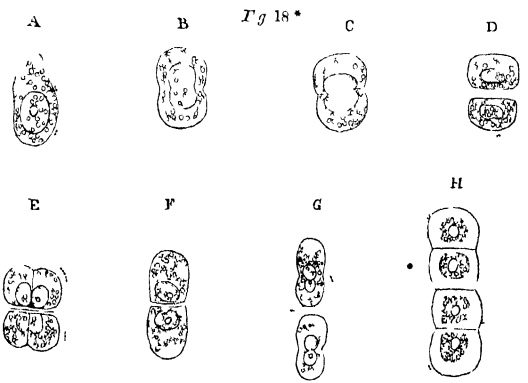
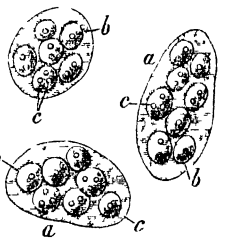


Fig 18 *

* Multiplication of Cartilage cells by duplication —A, original cell, B, the same beginning to divide, C, the same showing complete division of the nucleus, D, the same with the halves of the nucleus separated, and the cavity of the cell subdivided, E, continuation of the same process, with cleavage in *contrary* direction, to form a cluster of four cells, F, G, H, production of a longitudinal series of cells, by continuation of cleavage in the *same* direction.

example in the growth of Cartilage, which repeats in adult age the process by which the development of the 'germinal mass' takes place at the earliest period of embryonic life (CHAP. XI.). The process of subdivision seems to commence in the nucleus, which tends to separate itself into two equal parts; and each of these draws around it a portion of the contents of the cell, so that the cell-wall, which is at first merely inflected inwards by a sort of hour-glass contraction, at last forms a complete partition between the two halves of the original cavity (Fig. 18, A–D). The process of subdivision may be again repeated, either in the same or in a contrary direction, so as to produce four cells, either linearly arranged (F, G, H), or clustered together (E); and this duplication may take-place repeatedly, until a large mass has been produced by the subdivision of a single original cell.—In other cases, however, the nucleus appears to break-up at once into several fragments, each of which may draw around it a portion of the contents of the parent-cell, which becomes invested by a cell-wall of its own; and thus the cavity of the parent-cell may at once become filled with a whole brood of young cells, without any successive subdivision. Of this process we frequently have examples in the case of morbid growths, in which the multiplication of cells often takes-place with great rapidity (Fig. 19).—Generally speaking, the former method seems to prevail in structures which have a comparatively *permanent* destination; whilst the latter is adopted in cases in which the life of the cells thus generated is but *transitory*, or in which they are not destined to reproduce themselves. Thus the follicles of Glands (§ 238) are but parent-cells, in whose wall an opening has been formed for the liberation of the cells of the new generation (which are the real instruments of the secreting process) as fast as they are formed; successive crops of young cells being generated at their blind extremity, at the expense of the fresh materials which are continually drawn from the blood.

Fig 19.*



212. In the production of cells *de novo* in the midst of an organizable *blastema*, or plastic exudation, we cannot trace with the same distinctness the instrumentality of pre-existing cells. This blastema, when first effused, presents the appearance of a homogeneous, semi-fluid substance; as it solidifies, however, it becomes

* Parent-cells, *a*, *a*, of Cancerous structure, containing secondary cells, *b*, *b*, each having one, two, or three nuclei, *c*, *c*.

dimly shaded by minute dots; and as it is acquiring further consistence, some of these dots seem to aggregate, so as to form little round or oval clusters bearing a strong resemblance to cell-nuclei. These bodies appear to be the centres of the further changes which take-place in the blastema; for if it be about to undergo development into a *fibrous* tissue, they seem to be the centres from which the fibrillation takes place; whilst if a *cellular* structure is to be generated, it is from them that the cells take their origin. The first stage of the latter process appears to consist in the accumulation round each nucleus, of the substance which the cell is to include; and around this the cell-membrane is subsequently developed. Such is the mode, then, in which the development of new structures, for the filling-up of losses of substance, is provided-for; and it appears from the observations of Mr. Paget, that whilst the immediate *fibrillation* of the blastema takes-place in the case of effusions which are secluded from the air and which undergo organization under the most favourable circumstances, a production of *cells* takes-place when the blastema is poured-out upon the surface of an open wound, where the contact of air, and other sources of irritation, interfere with the organizing process, and occasion a tendency to degradation in the newly-generating tissue. The substance of granulations is almost entirely composed of such cells

Fig 20 *



(Fig. 20); of which the outer layers degenerate into pus-cells, whilst those forming the interior substance become converted into fibrous tissue (§ 193).

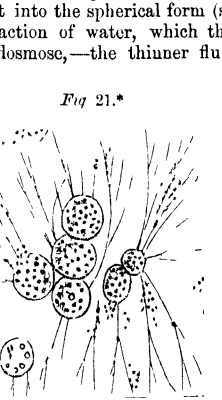
213. Such a production of cells *de novo* in the midst of an organizable blastema, does not constitute any real exception to the

* Granulation-cells, with imbedded capillary loop.

general rule, of the dependence of the life of every cell upon that of a pre-existing cell. For it is pretty certain that the blastema is itself the product of the formative agency of certain cells expressly provided for its elaboration; and it does not seem improbable that these cells, in bursting and setting-free the plastic fluid which they have prepared, should diffuse through it their own nuclear or germinal particles in a state of solution or extremely minute division; and that these, attracting each other in the act of solidification, should act as new centres of cell-growth, just as if they were still contained within the parent-cell.

214. The very simplest and most independent condition of the Animal Cell is probably to be found in the Blood, the Chyle, and the Lymph; in all of which liquids we meet with floating cells, which are completely isolated from one another, and which are consequently just as independent as the vesicles of the Red Snow or other simple cellular Plants. Indeed in the nature of their *habitat*, we may compare them with the Yeast-Plant; for as this will only vegetate in a saccharine fluid containing vegetable albumen, so do we find that these floating cells will only grow and multiply in the albuminous fluids of animals. In their general appearance, they very closely correspond with the figure already given as the *type* of the simple cell. Their diameter is pretty uniform in the different fluids of the body, and even in different animals; being for the most part about 1-3000th of an inch. They are sometimes nearly spherical, and sometimes flattened; when they present the latter shape, they may be made to swell-out into the spherical form (see *Frontispiece*, Figs. 4 and 5) by the action of water, which they imbibe according to the laws of Endosmose,—the thinner fluid, water, passing towards the more viscid contents of the cell, and mingling with them. By the continuance of this kind of action, the cell will be caused to burst. These cells, which are known as the corpuscles of the Chyle and Lymph, and as the *White* Corpuscles of the Blood, are observed to contain a number of minute molecules in their interior (*Front.* Fig. 4); and at a certain stage of their development,—probably that which immediately precedes the maturation and rupture of the parent-cell,—these molecules may be

Fig 21.*



* Colourless cells, with active molecules, and fibres of fibrin, from Herpes labialis.

seen, with a good Microscope, in active movement within the cavity. The action of a very dilute solution of potash causes the immediate rupture of these cells, and the discharge of the contained molecules, which are probably the germs of new cells of a similar character. And when they rupture spontaneously, which they are much disposed to do under the influence of contact with air, the fluid which they set-free shows an obvious tendency to assume a fibrous arrangement (Fig. 2).—The cells which are found in many fibrinous exudations, resemble the colourless corpuscles of the blood in all essential particulars (Fig. 21). Hence it may be concluded that they belong to the same class; being probably developed from granular germs set-free from the blood, along with the matter of the fibrinous exudation itself.

215. Besides the cells already mentioned, the blood of Vertebrated animals generally contains others, which are distinguished by their *red* colour and flattened form; these are altogether wanting, however, in the blood of the *Amphioxus* or Lancelet, which, although essentially a Fish, has many peculiarities that connect it with the lower divisions of the Animal series. The Red Corpuscles can scarcely be said to exist in the blood of Invertebrated animals; and their proportion in the blood of Vertebrata varies considerably in the several groups of that sub-kingdom. They present, in every instance, the form of a flattened disk, which is circular in Man and in most Mammalia (*Front.* Fig. 1), but which is oval in Birds, Reptiles, and Fishes, and in a few Mammals (*Front.* Fig. 6). These disks are in both instances flattened cells, whose walls are pellucid and colourless, but whose contents are coloured. Like the corpuscles already described, they may be caused to swell-up and burst by the imbibition of water; and the perfect transparency and the homogeneous character of their walls then become evident. (*Front.* Fig. 8, *e.*)—These Red corpuscles are not only distinguished from the others by the colour of their contents; they are also characterized by the absence of the separate molecules, which formed so distinctive a feature in the preceding; and in Oviparous Vertebrata, by the presence of a distinct central spot or *nucleus*, which appears to be composed of an aggregation of minute granules, analogous to those elsewhere diffused through the interior of the cell. The nucleus (where it exists) may be easily brought into distinct view by the action of acetic acid (§ 210); and it may also be obtained separate from the cell-wall and its contents, by treating the red corpuscles with water. The first effect of this is to render the nucleus rather more distinct, as is seen by contrasting the corpuscle which has been thus slightly acted-on (*Front.* Fig. 8, *a*), with the unaltered corpuscle (*Front.* Fig. 6) of the same animal. After a short time, the corpuscle swells-out and becomes more circular (*Front.* Fig. 8, *b*); and in a short time longer, the nucleus is seen, not in the centre of the disk, but near its margin (*Front.*

Fig. 8, *c*, *d*). Finally, the wall of the cell ruptures; the nucleus and its other contents are set-free; and whilst the colouring matter is diffused through the surrounding fluid, the cell-walls and the nuclei are separately distinguishable (*Front.* Fig. 8, *e*.)—It is remarkable, however, that the Red corpuscles of the blood of Mammals should possess no obvious nucleus; the dark spot which is seen in their centre (*Front.* Fig. 1), being merely an effect of refraction, in consequence of the double-concave form of the disk. When the corpuscles are treated with water, so that their form becomes first flat, and then double-convex, the dark spot disappears; whilst, on the other hand, it is made more evident when the concavity is increased by the partial emptying of the cell, which may be accomplished by treating the blood-corpuscles with fluids of *greater* density than their own contents.

216. The size of the Red Corpuscles is not altogether uniform in the same blood; thus it varies in that of Man from about 1-4000th to 1-2800th of an inch. But we generally find that there is an average size, which is pretty constantly maintained among the different individuals of the same species; that of the Human red corpuscles may be stated at about 1-3200th of an inch. The round corpuscles of the Mammalia do not in general depart very widely from this standard; except in the case of the Musk-Deer, in which they are less than 1-12,000th of an inch in diameter. It is in the Camel tribe alone, that we find oval corpuscles among Mammals; these have about the same average length as the round corpuscles of Man, but little more than half the breadth.—In Birds, the corpuscles are occasionally almost circular; but in general their diameters are to each other as $1\frac{1}{2}$ or 2 to 1. The size of the corpuscles is usually greater according to the size of the Bird; thus among the Ostrich tribe, the long diameter is about 1-1650th of an inch, and the short diameter 1-3000th; whilst among the small Sparrows, Finches, &c., the long diameter is about 1-2400th, and the short frequently does not exceed half that amount.—It is in Reptiles that we find the largest red corpuscles; and it is in their blood, therefore, that we can best study the characters of these bodies. The blood-disks of the Frog, from the facility with which they may be obtained, are particularly suitable for the purpose; their long diameter is about 1-1000th of an inch, whilst their short or transverse diameter is about 1-1800th. The curious Proteus, Siren, and other allied species, which retain their gills through their whole lives, are distinguished by the enormous size of their blood-disks. The long diameter of the corpuscles of the Proteus is about 1-337th of an inch; they are consequently almost distinguishable with the unaided eye. The long diameter of the corpuscles of the Siren is about 1-435th of an inch, and their short diameter about 1-800th; the long diameter of the nuclei of these corpuscles is about 1-1000th, and the short diameter about 1-2000th

of an inch,—so that the nuclei are about three times as long, and nearly twice as broad, as the entire human corpuscles.

217. The relation between the *White* or *Colourless*, and the *Red* Corpuscles of the Blood, can only be determined by attentively watching their development, and tracing them through all the stages of their growth. Although our knowledge on this subject is far from complete, yet there seems much reason to believe, from the observations of Mr. Wharton Jones on the different forms of blood-cells presented in the several classes of animals, and from those of Mr. Paget and other physiologists on the several gradations of structure exhibited in the blood-cells of Mammalia, that the *red* corpuscles have their origin in the *colourless*, and that the different forms of blood-cell presented in different groups of animals are, in fact, progressive stages in the same developmental process, which may be checked at any one of them.—Thus among the lower Invertebrata, the cells which are observed to float in their circulating fluid, seem to be little else than aggregations of granules, presenting a tuberculated surface; no cavity can be distinguished; and it is with difficulty that the presence of a distinct cell-wall can be demonstrated. This form, which is designated by Mr. Wharton Jones as the 'coarse granule-cell,' presents itself also among the chyle- and lymph-corpuscles of Vertebrated animals, and is occasionally met-with in their blood.—In other Invertebrata, the blood-cell undergoes a further development; for the cell-wall becomes more distinct, and the granules are so much more minute as to give to the entire cell a somewhat nebulous aspect, its surface being now smooth instead of tuberculated. This form of corpuscle, also, termed by Mr. Wharton Jones the 'fine granule-cell,' is found in the chyle and lymph, and occasionally in the blood, of Vertebrated animals.—The next stage in the history of development, is the aggregation of the granules into a distinct *nucleus*, and the clearing-up of the general cavity of the cell; and thus is formed the 'colourless nucleated cell,' which is the highest grade that the blood-cell attains in the Invertebrated series; the number of such cells being greater in each class, the closer is its approximation to the Vertebrated sub-kingdom. This phase presents itself also in the blood of Vertebrata, as a transition-stage between the chyle- and lymph-corpuscle, and the proper blood-disk or red-corpuscle.—Thus, then, we see that the cells which are found in the circulating fluid of Invertebrated animals, correspond rather with those of the Chyle and Lymph of Vertebrata, than with those which are characteristic of the Blood of the latter.

218. The next stage of development seems to consist in the acquirement of the peculiar red colour; and in the change of form, from the spherical to the flattened or discoidal. Thus is produced the 'coloured nucleated cell,' which is the characteristic grade of the blood-disk of the Oviparous Vertebrata in general. This grade

may be occasionally seen in the blood of the adult Mammal, as the transition-stage between the colourless nucleated cell, and the non-nucleated cells which are proper to it; but it is more easily made-out in the blood of the embryo.—The non-nucleated red corpuscles which are characteristic of Mammalia, are regarded by Mr. Wharton Jones as the escaped nuclei of the preceding, which have undergone development into cells; but it seems much more probable, that they are the same cells in a yet more advanced stage of development, the nuclei having been absorbed, as often happens in the case of other cells.

219. There can be no doubt that, like all other cells, each Blood-corpuscle has its proper term of life, and that it degenerates and dies when this is expired; if it were not, therefore, for the continual production of new cells, in the manner just described, the Blood would soon lose its due proportion of these components, since there is no reason to believe that the fully-formed red corpuscle can regenerate its kind, although multiplication by sub-division may take-place in an earlier stage of its development. When much blood has been drawn from the body, the proportion of red corpuscles in the remaining fluid is at first considerably lowered; the fluid portion of the blood being replaced almost immediately, whilst the floating cells require time for their regeneration. Their amount progressively increases, however, until it has reached its proper standard, provided that a due supply of the materials be afforded. We shall presently see that one of these materials is Iron; and it is well known that iron administered internally is an important aid in recovery from severe hemorrhages, as well as a valuable remedy for certain constitutional states, in which there is a diminished power of producing red corpuscles. Thus in Chlorosis, under the administration of iron, the amount of red corpuscles in the blood has been doubled within a short period. In the healthy state of the system, the continual production, and the continual death and disintegration, balance one another. In some instances (as in Chlorosis) the production is not sufficient to make-up for the loss by death; and the total amount in the blood undergoes an extraordinary diminution, sometimes even to less than a quarter of their proper proportion. In other cases, under the influence of excessive nutriment (as in the state termed Plethora), the proportion of Red Corpuscles is increased beyond the normal amount; and in this condition, the loss of a small quantity of blood may be a preservative from the evils to which it is incident, from Hemorrhage of various kinds.

220. The Red Corpuscles make their first appearance in the blood of the Embryo, however, long before the formation of chyle and lymph commences; and they appear to be formed by the metamorphosis of some of the cells which constitute the inner layer of the germinal membrane (CHAP. XI.). These cells are at first nearly

spherical, and are full of particles of a yellowish substance like fatty matter; in the midst of which, though somewhat obscured by them, a central nucleus may be seen. The development of these embryo-cells into the oval red-corpuscles of the Oviparous Vertebrata, is stated by Mr. Paget to be effected by the gradual clearing-up, as if by division and liquefaction, of the contained particles, the acquirement of the blood-colour and of the elliptical form, the flattening of the cell, and the more prominent appearance of the nucleus. This first set of blood-disks is nucleated in Mammalia, as well as in Oviparous Vertebrata; and they occasionally present indications of being in course of multiplication by subdivision. They gradually disappear from the blood, however, when the chyle- and lymph-corpuscles first present themselves in the circulating current; and thenceforth the Red corpuscles seem to be formed at the expense of the latter alone. It is curious that this change should usually coincide, in the Tadpole, with the time at which the external branchiæ disappear (§ 562); and, in warm-blooded animals, with the period at which the branchial fissures are closed in the neck, and the course of the circulation is altered (§ 566).

221. The chemical composition of the Red corpuscles presents certain peculiarities which require notice. They contain about 312 parts in 1000 of solid matter; and of this amount, the cell-walls constitute about 41½ parts, while the cell-contents hold the remaining 270½ parts. These contents, which may be obtained by treating the Red corpuscles with water (§ 215), yield—besides about 5 parts of fatty and extractive matters, and 8 parts of mineral matter—257½ parts of the peculiar substance to which the colour of the corpuscles is due, and which has the remarkable property of crystallizing when set-free. It is generally considered to be a mixture of two distinct compounds, *globulin* and *hæmatin;* the former being a colourless albuminoid substance, whilst the latter is deeply coloured; and though it is doubtful whether these have a distinct existence until the substance which yields them has been subjected to chemical treatment, yet it seems desirable to describe them separately.—The *globulin* of the blood-corpuscles is not identical (as was formerly supposed) with that of the crystalline lens; and as it is by it that the blood-crystals are formed, Lehmann proposes to designate it as *hæmato-crystallin.* It is remarkable that the crystals obtainable from the blood of different animals should belong to different systems: thus, those of man and the carnivora generally have a prismatic form, whilst those of the rat and mouse are tetrahedral, those of the squirrel hexagonal plates, and those of the hamster rhombohedral. Hence it would seem that there must be some minute differences between the hæmato-crystallin of the blood-corpuscles of these several animals, though no difference in composition or reactions can be detected. Its ultimate constituents appear to bear the same proportions to each other as

they do in albuminoid substances generally; but hæmato-crystallin differs from these in not being precipitated from its solution by nitrate of silver, bichloride of mercury, chloride of zinc, or sub-acetate of lead, whilst it is thrown-down by protonitrate of mercury and bichromate of potass. When submitted to the action of heat, hæmato-crystallin coagulates between 145° and 149°. Its crystals are usually deeply tinged by the colouring matter to be next described, and cannot be freed from it without much difficulty. —The composition of *Hæmatin* is notably different from that of the albuminoid compounds; the proportion of carbon to the other ingredients being very much greater; and a definite quantity of iron being an essential part of it. Its formula is 44 Carbon, 22 Hydrogen, 3 Nitrogen, 6 Oxygen, and 1 Iron. When completely separated from Albuminous matter, it is a dark brown substance, incapable of coagulation, nearly insoluble in water, alcohol, ether, acids, or alkalies, alone; but readily soluble in alcohol mixed either with sulphuric acid or ammonia. The solution, even when diluted, has a dark colour; and possesses all the properties of the colouring matter of venous blood. The iron may be separated from the hæmatin by strong reagents which combine with the former; and the latter still possesses its characteristic colour. This hue cannot be dependent, therefore, on the presence of iron in the state of peroxide; as some have supposed. On the other hand, the iron is most certainly united firmly with the ingredients of the hæmatin, as contained in the red corpuscles; for this may be digested in dilute sulphuric or muriatic acid for many days, without the least diminution in the quantity of iron, the usual amount of which may be afterwards obtained by combustion from the hæmatin that has been subjected to this treatment. This experiment seems further to prove, that the iron cannot be united with the hæmatin in the state of either protoxide or peroxide, as maintained by Liebig; since weak acids would then dissolve it out. Regarding the nature of this compound, and the changes which it undergoes in respiration, there is still much to be learned; and until these points have been more fully elucidated, the precise uses of the Red corpuscles in the animal œconomy cannot be understood. There is evidence, however, that the production of Hæmatin is (like the production of the red colouring matter of the *Protococcus*, § 31), a result of chemical action taking place in the cells themselves; for no substance resembling Hæmatin can be found in the liquid in which these cells float, and scarcely a trace of iron can be detected in it; whilst, on the other hand, the fluid portion of the chyle holds a large quantity of iron in solution, which seems to be drawn into the red corpuscles, and united with the other constituents of hæmatine, as soon as ever it is delivered into the circulating current.

222. It has been usually supposed, until recently, that the

difference in colour between Arterial and Venous blood is solely due to different states of combination of the Hæmatin they respectively contain, with Oxygen and Carbonic acid. For in its passage through the capillaries of the system, the arterial blood loses its bright florid hue, and assumes the dark purple tint which distinguishes ordinary venous blood; and the converse change takes-place in the capillaries of the lungs, the original florid hue being recovered. Now it is certain that the blood, in its change from the arterial to the venous condition, loses oxygen, and becomes charged with an increased amount of carbonic acid, although its precise mode of combination is not known; on the other hand, in its return from the venous to the arterial state, the blood gives-off this additional charge of carbonic acid, and imbibes oxygen. The change of colour, under similar conditions, takes-place out of the body, as well as in it. Thus if venous blood be exposed for a short time to the air, its *surface* becomes florid; and the non-extension of this change to the interior of the mass, is evidently due to the impossibility of bringing air into relation with every particle of the blood, in the manner which the lungs are so admirably contrived to effect. If venous blood be exposed to pure oxygen, the change of colour will take-place still more speedily; and it is not prevented by the interposition of a thick animal membrane, such as a bladder, between the blood and the gas. On the other hand, if arterial blood be exposed to carbonic acid, it loses its brilliant hue, and is rendered as dark as venous blood; or even darker, if exposed very completely to its influence. The simple removal of this carbonic acid is not sufficient to restore the original colour; for this removal may be effected by hydrogen, which has the power of dissolving-out (so to speak) the carbonic acid diffused through the blood, without the restoration of the arterial hue, which does not return unless oxygen be present, or saline matter be added to the blood.—Recent observations seem to render it probable that these variations are due, not so much to changes of *composition* in the Hæmatin, as to changes of *form* in the Corpuscles which contain it. For it appears that the effect of oxygen, like that of saline solutions, is to contract the corpuscles and to thicken their walls, so as, by altering their mode of reflecting light, to make them appear bright-red; whilst carbonic acid, like water, may be seen to occasion a dilatation of the corpuscle, and a thinning of its walls (which are at last dissolved by it), in a degree that is nearly sufficient to account for the darkening of the hue of the mass. Still it is certain that a solution of Hæmato-crystallin, in which no corpuscles are present, and which is coloured by the presence of Hæmatin, is brightened by oxygen and darkened by carbonic acid; so that the chemical action of these gases must have some share in the changes of colour which the blood undergoes.

223. The Red corpuscles have undoubtedly a far greater absorp-

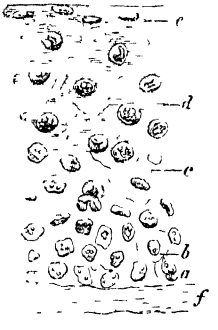
tive power for oxygen and carbonic acid, than is possessed by the fluid in which they float; for defibrinated blood, which contains the corpuscles, absorbs 1½ times its volume of carbonic acid, and 15 per cent. of oxygen; whilst serum deprived of corpuscles absorbs very little more than water, which takes-up only its own volume of carbonic acid, and less than 1 per cent. of oxygen. This circumstance, taken in connexion with the fact that these bodies are almost completely restricted to the blood of Vertebrata (whose respiration is much more energetic than that of any Invertebrated animals save Insects, which have a special provision of a different character), and that their proportion to the whole mass of the blood corresponds with the activity of the respiratory function,—leave little doubt that they are actively (though not exclusively) concerned as *carriers* of Oxygen from the lungs to the tissues, and of Carbonic acid from the tissues to the lungs.—What may be the relation of the Red corpuscles, however, to the function of Nutrition, is more questionable. But it can scarcely be regarded as otherwise than a very significant circumstance, that the phosphorized fats which seem destined to form the *pabulum* of the Nervous tissue, and the potass which is a most characteristic component of the Muscular, should be almost entirely limited to their contents, being scarcely discoverable in the serum. The grey matter of the Nervous centres, moreover, in common with muscular fibre generally, contains a pigmentary matter closely allied to Hæmatin. Hence it seems not altogether improbable, that the Red corpuscles may have it as one of their offices to prepare the nutrient materials for these tissues by an assimilating process; and this idea is also in accordance with the fact, that they are most numerous in those Vertebrata which are most distinguished by their nervo-muscular activity.

224. Next in independence to the cells or corpuscles floating in the animal fluids, are those which cover the free membranous surfaces of the body, and form the *Epidermis* and *Epithelium*. Between these two structures there is no more real difference, than there is between the Skin and the Mucous membranes. The one is continuous with the other; they are both formed of the same elements; they are cast-off and renewed in the same manner; the history of the life of the individual cells of each is nearly identical; but there is an important difference in the purposes which they respectively serve in the general economy.

225. The *Epidermis* or Cuticle covers the exterior surfaces of the body, as a thin semitransparent pellicle, which is apparently homogeneous in its texture, is not traversed by vessels or nerves, and was formerly supposed to be an inorganic exudation from the surface of the true Skin, designed for its protection. It is now known, however, to consist of a series of layers of cells, which are continually wearing-off at the external surface, and are being

renewed at the surface of the true skin; so that the newest and deepest layers gradually become the oldest and most superficial, and are at last thrown-off by slow desquamation. Occasionally this desquamation of the cuticle is much more rapid; as after Scarlatina, and other inflammatory affections of the Skin.—In their progress from the internal to the external surface of the Epidermis, the cells undergo a series of well-marked changes. When we examine the innermost layer, we find it soft and granular; consisting of *nuclei*, in various stages of development into cells, held together by a tenacious semi-fluid substance. This was formerly considered as a distinct tissue, and was supposed to be the peculiar seat of the colour of the skin; it received the designation of *rete mucosum*. Passing outwards, we find the cells more completely formed; at first nearly spherical in shape; but becoming polygonal where they are flattened against one another. As we approach the surface, we perceive that the cells are gradually more and more flattened, until they become mere horny scales, their cavity being obliterated; their origin is indicated, however, by the nucleus in the centre of each. This flattening appears to result from the gradual desiccation or drying-up of the contents of the cells, which results from their exposure to the air. Thus each cell of the Epidermis is developed from the nucleus on the surface of the basement-membrane (which nucleus probably forms itself in the plasma that is exuded from the subjacent vessels, § 212), and is gradually brought to the surface by the development of new cells beneath, and the removal of the superficial layers; whilst at the same time it is progressively changed in form, until it is converted into a flattened scale. The accompanying representation (Fig. 22) of an oblique section of the Epidermis, exhibits the principal gradations of its component structures.

Fig. 22.*

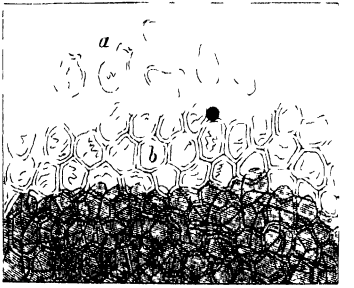


226. The Epidermis covers the whole exterior surface of the body; not excepting the Conjunctiva of the eye, on which, however, it has more the character of an Epithelium, and the Cornea, on which it

* Oblique section of Epidermis, showing the progressive development of its component cells. —*a*, nuclei, resting upon the surface of the cutis vera, *f*; these nuclei are seen to be gradually developed into cells, at *b*, *c*, and *d*; and the cells are flattened into lamellæ, forming the exterior portion of the epidermis at *e*.

participates in the horny character of the Epidermic covering (Fig. 23). The continuity is well seen in the cast skin or *slough* of the Snake; in which the covering of the front of the eye is found to be as perfectly exuviated, as is that of any part of the body. The number of layers varies greatly in different parts; being usually found to be the greatest where there is most pressure or friction.

Fig. 23.*



Thus on the soles of the feet, particularly at the heel and the ball of the great toe, the Epidermis is extremely thick; and the palms of the hands of the labouring man are distinguished by the increased density of their horny covering. It would seem as if the irritation of the Skin stimulated it to an increased production of this substance. The Epidermic membrane is pierced by the excretory ducts of the sweat-glands and of the sebaceous follicles, which lie in the true skin and immediately beneath it; or we should rather say that it is continuous with the delicate epithelial lining of these.—The *Nails* may be considered as nothing more than an altered form of Epidermis. When examined near their origin, they are found to consist of cells which gradually dry into scales; and these remain coherent together. A new production is continually taking-place in the groove of the skin in which the root of the nail is imbedded, and also from the whole subjacent surface: the former adds to the length of the nail, and the latter to its thickness.

227. The Epidermis, when analysed, is found to differ from the protein-compounds in its composition; but not in any very striking degree. The proportion of its elements is considered to be 48 Carbon, 39 Hydrogen, 7 Nitrogen, 17 Oxygen; and this corresponds exactly with the composition of the substance of which Nails, Horn,

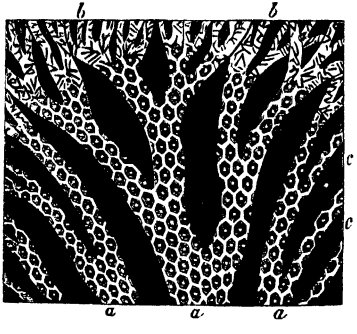
* Horny Epidermis, from Conjunctiva covering the Cornea; *a*, single scales; *b*, single lamina of epithelium; below is seen a double layer of the same.

Hair, and Wool are constituted. It seems probable, however, that the *cell-walls* possess, as elsewhere, an Albuminoid composition; and that the horny matter is a secretion in their interior, which is drawn from the elements of blood during their growth and development.

228. The Epidermis appears solely destined for the *protection* of the true Skin, both from the mechanical injury and the pain which the slightest abrasion would produce, and from the irritating effects of exposure to the external air and of changes of temperature. We perceive the value of this protection, when the Epidermis has been accidentally removed. It is very speedily replaced, however; the increased determination of blood to the Skin, which is the consequence of the irritation, being favourable to the rapid production of Epidermic cells on its surface.

229. Mingled with the Epidermic cells, we find others which secrete colouring matter instead of horn; these are termed *Pigment-cells*. They are not readily distinguishable in the epidermis of the White races, except in certain parts, such as the areola around the nipple, and in freckles, nævi, &c. But they are very obvious, on account of their dark hue, in the newer layers of the Epidermis of the Negro and other coloured races; and, like the true Epidermic cells, they dry-up and become flattened scales in their passage towards the surface, thus constantly remaining dispersed through the Epidermis, and giving it a dark tint when it is separated and held-up to the light. In all races of men, however, we find the most remarkable development of Pigment-cells on the inner surface

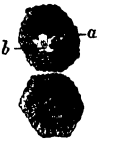
Fig. 21*



* A portion of the Choroid coat from the eye of the Ox, showing the Pigment-cells, where they cover *a*, *a*, *a*, the veins, in a single layer; *b*, *b*, ramifications of the veins near the ciliary ligament, covered with less regular pigment-cells; *c*, *c*, spaces between the vessels, more thickly covered with pigment-cells.

of the Choroid coat of the eye, where they form several layers, known as the *Pigmentum nigrum*. Here they have a very regular arrangement; which is best seen where they cover the blood-vessels of the Choroid coat in a single layer, as shown in Fig. 24. When examined separately, they are found to have a polygonal form (Fig. 25, *a*), and to have a distinct nucleus (*b*) in their interior. The black colour is given by the accumulation, within the cell, of a number of flat rounded or oval granules, measuring about 1-20,000th of an inch in diameter, and a quarter as much in thickness; these, when separately viewed, are observed to be transparent, not black and opaque; and they exhibit an active movement when set-free from the cell, and even whilst enclosed within it. The pigment-cells are not always of a simple rounded or polygonal form; they sometimes present remarkable stellate prolongations, under which form they are well seen in the skin of the Frog.—The Chemical nature of the black pigment has not yet been made evident; it has been shown, however, to have a close relation with that of the Cuttle-fish ink or Sepia, which derives its colour from the pigment-cells lining the ink-bag; and to include a larger proportion of Carbon than most other organic substances,—every 100 parts containing 58½ of this element.

Fig. 25.*



230. That the development of the pigment-cells, or at least the formation of their peculiar secretion, is in some degree due to the influence of Light, seems evident from the facts already mentioned (§ 93). To these it may be added, that the new-born infants of the Negro and other dark races do not exhibit nearly the same depth of colour in their skins, as that which they present after the lapse of a few days; which seems to indicate that exposure to light is necessary for the full development of the characteristic hue. An occasional development of dark pigment-cells takes place during pregnancy in some females of the fair races; thus it is very common to meet with an extremely dark and broad areola round the nipple of pregnant women; and sometimes large patches of the cutaneous surface, on the lower part of the body especially, become almost as dark as the skin of the Negro. On the other hand, individuals are occasionally seen with an entire deficiency of pigment-cells, or at least of their proper secretion, not merely in the skin, but in the eye; such are termed Albinoes; and they are met-with as well among the fair, as among the dark races. The absence of colour usually shows itself also in the hair; which is almost white.

231. The *Epithelium* may be designated as a delicate cuticle, covering the free *internal* surfaces of the body, and apparently

* Detached Pigment-cells, magnified 300 diameters;—*a*, cell; *b*, nucleus.

designed, in some instances, simply for their protection; whilst in other cases, as we shall presently find, it serves purposes of far greater importance. It has long been known that the Epidermis might be traced continuously from the lips to the mucous membrane of the mouth, and thence down the œsophagus into the stomach; and that in the strong muscular stomach or gizzard of the granivorous birds, it becomes quite a firm horny lining. But it has been only ascertained by the use of the Microscope, that a continuous layer of cells may be traced, not merely along the whole surface of the mucous membrane lining the alimentary canal, but likewise along the free surfaces of all other Mucous membranes, with their prolongations into follicles and glands; as well as on Serous and Synovial membranes, and on the lining membrane of the heart, blood-vessels, and absorbents. The Epithelial cells, being always in contact with fluids, do not dry up into scales like those of the Epidermis; and they differ from them also in regard to the nature of the matter which they secrete in their interior. In this respect, however, the Epithelial cells of different parts are unlike one another, fully as much as any of them are unlike the cells of the Epidermis; for we shall find that *all* the secretions of the body are the product of the elaboration of Epithelium-cells; and consequently there are as many varieties of endowment in these important bodies, as there are varieties in the result of their action.

232. The Epithelium covering the Serous and Synovial membranes, and the lining of the blood-vessels, is composed of flattened polygonal cells (resembling those shown in Fig. 36), lying in apposition with each other, so as to form a kind of pavement; hence this form is termed *pavement-* or *tesselated*-Epithelium. There is no reason to believe that it possesses any active endowments in these situations; since it does not appear to be concerned in the elaboration of any peculiar secretion. It has been already pointed-out (§ 196), that the fluid of serous membranes is separated from the blood by a simple act of mechanical transudation (which often takes place to a great extent after death); the walls of the blood-vessels do not appear to be concerned in forming any peculiar secretion; and the only product of this kind, which indicates any special endowment in the epithelium-cells, is the synovia, which is probably elaborated by the cells covering the vascular fringes of the synovial membrane, formerly mentioned (§ 198). The cells draw it from the blood, during the progress of their growth, form it as a secretion within themselves, and then cast it into the general cavity of the joint (when their term of individual life is ended), either by the rupture or the liquefaction of their walls. In other cases, it would seem as if the epithelial cells were not frequently cast-off and renewed, but possessed a considerable permanency. It is to be remembered that, in the healthy state of the serous and synovial membranes, and in that of the lining membrane of the blood-

vessels and absorbents, they are entirely secluded from sources of irritation; and that they lead a sort of *passive* life, very different from the *active* life of the mucous membranes. In fact, it would appear to be the sole object of the serous membranes, to enclose and suspend the viscera, in such a manner as to allow of the access of blood-vessels, nerves, gland-ducts, &c.; and at the same time to permit them the required freedom of motion, and to provide against the irritation of opposing parts, by furnishing an extremely smooth and moistened surface, wherever friction takes place. Hence we find membranes, with all the characters of serous surfaces, in the false joints formed by un-united fractures, and in other similar situations.

233. The Epithelium of the Mucous membranes and their prolongations, is found under two principal forms, the *tesselated*, and the *cylindrical*. An example of the Tesselated form is seen in Fig. 26, which shows the separate epithelium-cells of the mucous membrane of the mouth, as they are frequently met-with in saliva. The cells are not always so polygonal in form, however; sometimes retaining their rounded or oval form, and being separated by considerable interstices, so that they can scarcely be said to form a continuous layer. A specimen of this kind is seen in Fig. 27,

Fig. 26 *

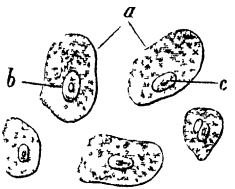


Fig 27 †



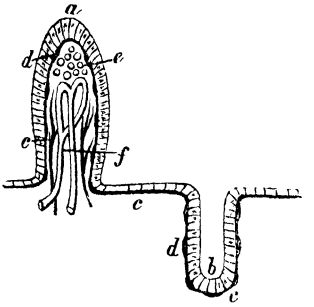
which represents a group of epithelium-cells from one of the smaller bronchial tubes. This form of tesselated epithelium is more commonly met-with, where the secreting operations are more active, the life of the cells consequently shorter, and the renewal of them more frequent; so that they have not time, so to speak, to be developed into a more continuous layer.—The Cylinder-Epithelium is very differently constituted. Its component cells are cylinders, which are arranged side by side; one extremity of each cylinder resting upon the basement-membrane, whilst the other forms part

* Detached Epithelium-cells, *a*, with nuclei, *b*, and nucleoli, *c*, from mucous membrane of mouth.

† Pavement-Epithelium of the Mucous Membrane of the smaller bronchial tubes; *a*, nuclei with double nucleoli.

of the free surface. The perfect cylindrical form is only shown, when the surface on which the cylinders rest is flat or nearly so. When it is *convex*, the lower ends or bases of the cells are of much smaller diameter than the upper or free extremities; and thus each has the form of a truncated cone, rather than of a cylinder; as is well seen in the cells which cover the *villi* of the intestinal canal (Fig. 28, *a*). On the other hand, where the cylinder-epithelium

Fig. 28.*



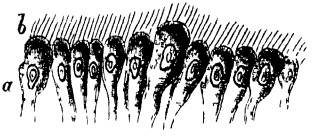
lies upon a *concave* surface, the free extremities of the cells may be smaller than those which are attached (*b*). Sometimes each cylinder is formed from more than one cell, as is shown by the nuclei it contains; although its cavity seems to be continuous from end to end. And occasionally the cylinders arise by stalk-like prolongations, from a tesselated epithelium beneath. The two forms of Epithelium pass into one another at various points; and various transitional forms are then seen,—the tesselated scales appearing to rise more and more from the surface, until they project as long-stalked cells, truncated cones, or cylinders.

234. Both these principal forms of Epithelial cells are frequently observed to be fringed at their free margins with delicate filaments, which are termed *cilia;* and these, although of extreme minuteness, are organs of great importance in the animal economy, through the extraordinary motor powers with which they are endowed. The form of the ciliary filaments is usually a little flattened, and tapering gradually from the base to the point. Their size is extremely variable; the largest that have been observed being about 1-500th of an inch in length, and the smallest about 1-13,000th. When in

* Diagram of Mucous Membrane of Jejunum;—*a*, epithelium of a villus; *b*, secreting epithelium of a follicle; *c*, *d*, basement membrane; *e*, areolæ for the reception of chyle; *f*, vessels and lacteals of villus.

motion, each filament appears to bend from its root to its point, returning again to its original state, like the stalks of corn when depressed by the wind; and when a number are affected in succes-

Fig. 29.*



sion with this motion, the appearance of progressive waves following one another is produced, as when a cornfield is agitated by frequent gusts. When the ciliary motion is taking place in full activity, however, nothing whatever can be distinguished, save the whirl of particles in the surrounding fluid; and it is only when the rate of movement slackens, that the shape and size of the cilia, and the manner in which their stroke is made, can be clearly seen. The motion of the cilia is not only quite independent (in all the higher animals at least) of the will of the animal, but is also independent even of the life of the rest of the body; being seen after the death of the animal, and proceeding with perfect regularity in parts separated from the body. Thus isolated epithelium-cells have been seen to swim-about actively in water, by the agency of their cilia, for some hours after they have been detached from the mucous surface of the nose; and the ciliary movement has been seen fifteen days after death in the body of a Tortoise, in which putrefaction was far advanced. In the gills of the River-Mussel, which are among the best objects for the study of it, the movement endures with similar pertinacity.

235. The purpose of this ciliary movement is obviously to propel fluids over the surface on which it takes place; and it is consequently limited in the higher animals to the internal surfaces of the body, and always takes place in the direction of the outlets, towards which it aids in propelling the various products of secretion. The case is different, however, among animals of the lower classes, especially those inhabiting the water. Thus the external surface of the gills of Fishes, Tadpoles, &c., is furnished with cilia; the continual movement of which renews the water in contact with them, and thus promotes the aeration of the blood. In the lower Mollusca, and in many Zoophytes, which pass their lives rooted to one spot, the motion of the cilia serves not merely to produce currents for respiration, but likewise to draw into the mouth the

* Vibratile or Ciliated Epithelium;—*a*, nucleated cells, resting on their smaller extremities; *b*, cilia.

minute particles that serve as food. And in the free-moving Animalcules, of various kinds, the cilia are the sole instruments which they possess, not merely for producing those currents in the water which may bring them the requisite supply of air and food, but also for propelling their own bodies through the water. This is the case, too, with many larger animals of the class Acalephæ (Jelly-fish), which move through the water, sometimes with great activity, by the combined action of the vast numbers of cilia that clothe the margins of their external surfaces. In these latter cases, it would seem as if the ciliary movement were more under the control of the will of the animal, than it is where concerned only in the organic functions. In what way the will can influence it, however, it does not seem easy to say; since the ciliated epithelium-cells appear to be perfectly disconnected from the surface on which they lie, and cannot, therefore, receive any direct influence from their nerves. Of the cause of the movement of the cilia themselves, no account can be given; they are usually far too small to contain even the minutest fibrillæ of muscle; and we must regard them as being, like those fibrillæ, organs *sui generis*, having their own peculiar endowment,—which is, in the higher animals at least, that of continuing in ceaseless vibration, during the whole term of the life of the cells to which they are attached. The length of time during which the ciliary movement continues after the general death of the body, is much less in the warm-blooded than in the cold-blooded animals; and in this respect it corresponds with the degree of persistence of muscular irritability, and of other vital endowments.

236. The Tesselated-Epithelium, as already mentioned, covers the Serous and Synovial membranes, the lining membrane of the blood-vessels and absorbents, and the Mucous membranes with their glandular prolongations, except where the cylinder-epithelium exists. It presents itself, with some modifications presently to be noticed, in the ultimate follicles of all glands, and also in the smaller bronchial tubes. In this latter situation it is furnished with cilia: and these are also found in the cells of the tesselated epithelium which covers the delicate pia mater lining the cerebral cavities.—The Cylinder-Epithelium commences at the cardiac orifice of the stomach, and lines the whole intestinal tube; and, generally speaking, it lines the larger gland-ducts, giving place to the tesselated form in their smaller ramifications.—A similar epithelium, furnished with cilia, is found lining the air-passages and their various offsets,—the nasal cavities, frontal sinuses, maxillary antra, lachrymal ducts and sac, the posterior surface of the pendulous velum of the palate and fauces, the eustachian tubes, the larynx, trachea, and bronchi,—becoming continuous, however, in the finer divisions of the latter, with the ciliated pavement-epithelium. The upper part of the vagina, the uterus, and the fallopian tubes, are also furnished with a ciliated Cylinder-Epithelium. The function

of the cilia in all these cases appears to be the same; that of propelling the viscid secretions, which would otherwise accumulate on these membranes, towards the exterior orifices whence they may be carried-off.

237. The simplest office which the Epithelium-cells of Mucous membranes perform, appears to be that of elaborating a peculiar secretion termed *Mucus;* which is destined to protect them from the contact of air, or from that of the various irritating substances to which they are exposed, in consequence of their peculiar position and functions. This Mucus is a transparent semifluid substance, distinguished by its peculiar tenacity or viscidity. It is quite insoluble in water; but is readily dissolved by dilute alkaline solutions, from which it is precipitated again by the addition of an acid. A substance resembling Mucus may be produced from any fibrinous exudation, or even from pus, by treating it with a small quantity of liquor potassæ. The secretion of Mucus, like the formation of Epidermis, appears to take place with an activity proportioned to the afflux of blood to the subjacent membrane. On many parts of the mucous surface, a sufficient supply is afforded by the epithelium-cells which cover it; but in other situations, especially along the alimentary canal, the demand is much greater, and it is probably supplied not merely by the cells of the surface, but by those lining the crypts or follicles which are formed by involutions of it.

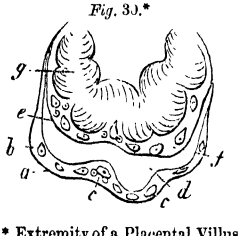
238. The Epithelium-cells covering the intestinal *villi* are most important agents in the function of Absorption, for which those organs are specially destined. These villi are root-like prolongations of the mucous membrane, which are thickly set upon the lining membrane of the small intestine, commencing at the point at which the biliary and pancreatic ducts enter it; they are copiously supplied with blood-vessels (Fig. 13, p. 127); and they contain in their interior one or more lacteal tubes (Fig. 28, *f*), the former taking up any substances that are in complete solution, whilst the latter only receive a liquid of peculiar composition, selected from the contents of the intestinal tube, which is known as *chyle.* The absorbent process by which nutritious and other substances are drawn into the blood-current, will be shown hereafter (§ 492) to be of a purely physical nature; but the selection of the materials of Chyle appears to be dependent upon the vital endowments of the Epithelial cells covering the ends of the villi. These, during digestion, become turgid with a milky opalescent fluid, their form and aspect being so completely changed that they have been supposed to be new cells developed for the purpose of absorption, the ordinary epithelium being cast-off,—which has now, however, been clearly proved not to be the case. When they have thus drawn into themselves the chylous fluid, they impart it to the lacteal imbedded in the villus; the fluid finding its way by transudation

through the basement-membrane into a lax tissue beneath, where there seem to be areolar spaces (Fig. 28, *e*) for its reception, in the midst of which the lacteal originates. During the intervals of digestion, the epithelial cells covering the villi return to their ordinary form.

239. Although the Mucous membrane of the intestinal tube is the only channel through which insoluble nutriment can be absorbed in the completely-formed Mammal, and the only situation, therefore, in which we meet with these absorbent cells, there are other situations in which similar cells perform analogous duties in the embryo. Thus the Chick derives its nutriment, whilst in the egg, from the substance of the yolk, by absorption through the blood-vessels spread-out in the vascular layer of the germinal membrane surrounding the yolk; which vessels answer to the blood-vessels and lacteals of the permanent digestive cavity, and are raised into folds or villi as the contents of the yolk-bag are diminished. Now the ends of the vessels are separated from the fluid contents of the yolk-bag, by a layer of cells; which seems to have for its object to select and prepare the materials supplied by the yolk, for being received into the absorbent vessels.

240. In like manner, the embryo of the Mammal is nourished, up to the time of its birth, through the medium of its umbilical vessels; the ramifications of which form tufts, that dip-down, as it were, into the maternal blood, and receive from it the materials destined to the nutrition of the fœtus; besides effecting the aeration of the blood of the latter, by exposing it to the more oxygenated blood of the mother (§ 819). Now around the capillary loop of the fœtal tuft, there is a layer of cells, closely resembling the absorbent cells of the villi, save that they are enclosed in a cap of basement-membrane, which completes the fœtal portion of the tuft. It is again surrounded, however, by another layer of membrane and of cells, belonging to the maternal system;—the derivation and arrangement of which will be explained hereafter (CHAP. XI.). The maternal cells (*b*, Fig. 30) may be regarded as the first selectors of nutriment from the circulating fluid of the parent: the materials, partially prepared by them, are poured into the cavity

Fig. 30.*



* Extremity of a Placental Villus:—*a*, external membrane of the villus, continuous with the lining membrane of the vascular system of the mother; *b*, *c*, external cells of the villus, belonging to the placental decidua; *d*, the space between the maternal and fœtal portions of the villus; *e*, the internal membrane of the villus, continuous with the external membrane of the chorion; *f*, the internal cells of the villus, belonging to the chorion; *g*, the loop of umbilical vessels.

(*d*) surrounding the extremity of the tuft; and from this they are taken-up by the fœtal cells (*f*), which further elaborate them, and impart them to the capillary loop (*g*) of the umbilical vessels.

241. The Epithelium-cells which are found in the interior of glandular follicles, seem usually rather to occupy their cavity than merely to line their walls, and appear to be in course of continual production from the blind extremity of the follicle. This is the case alike in regard to the simple follicles or crypts of mucous membranes, and to the ultimate follicles of the more complex glands, which may be regarded as so many repetitions of them;—the only difference being, that the latter pour their secretion into a branch of a duct, which unites with the other ramifications to form a trunk; and this trunk conveys them to their destination in some cavity lined by a mucous membrane;—whilst the simple follicles or crypts at once pour-forth their secretion upon the surface of the membrane. The accompanying figure (31) represents two follicles of the

Fig. 31.*

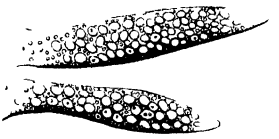
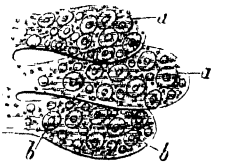


Fig. 32 †



liver of the common Crab, which are seen to be filled with secreting cells; it seems evident, from the comparative sizes of these cells in different parts, that they originate at the blind extremity of the follicle, and that, as they recede from that spot, they gradually increase in size, and become filled with their characteristic secretion, being at the same time pushed-onwards towards the outlet by the continual new growth of cells at the point of origin. In Fig. 32 are shown the corresponding ultimate follicles of the Mammary gland, filled, like the preceding, with secreting cells.

242. The whole of the acts, then, by which the separation of the different Secretions from the Circulating fluid is accomplished, really consist in the growth and nutrition of a certain set of cells, usually covering the free surfaces of the body, both internal and external, or lining cavities which have a ready communication with

* Two follicles from the Liver of *Carcinus mœnas* (Common Crab), with their contained secreting cells.

† Ultimate follicles of Mammary gland, with their secreting cells, *a*, *a*,—*b*, *b*, the nuclei.

these by means of ducts or canals.* These cells differ widely from one another, in regard to the kind of matter which they appropriate and assemble in their cavities; although the nature of their walls is probably the same throughout. Thus we find biliary and fatty matters, easily recognizable by their colour and refracting power, in the cells of the liver (Fig. 33); milk in the cells of the Mammary gland (Fig. 32); sebaceous or fatty matter in the cells of the sebaceous follicles of the skin; and so on. All these substances are derived from the blood; being either contained in it previously, or being elaborated from its constituents by a simple process of transformation,—as, for example, that which converts the albumen of the blood into the casein of milk. Hence they may be considered as the peculiar aliments of the several groups of cells; whose acts of *nutrition* are the means of drawing them off, or *secreting* them, from the general circulating fluid. When these cells have attained their full growth and accomplished their term of life, their walls frequently burst or dissolve-away, so that the contents of the cells are delivered into the cavity, or upon the surface, at which they are required; but in some instances (especially in the case of the epithelial cells of the urinary tubules), they seem to allow the continual transudation of their contents on their free surface, without any rupture of their own walls, into the cavity which they line. Now as all the canals of the glands open either directly outwards upon the surface, or into cavities which communicate with the exterior, it is evident that the various products of the action of these epithelial cells must be destined to be cast-forth from the body. This we shall find to be the case: some of them, as the bile and urine, being excretions, of which it is necessary to get rid by the most direct channel; whilst others, like the tears, the saliva, the gastric fluid, the milk, &c., are separated from the blood, not so much for *its* purification, but because *they* are required to answer certain purposes in the economy.

Fig. 33.†



243. Now whilst thus actively concerned in the Nutritive functions of the economy, and exercising in the highest degree their powers of selection and transformation, these Secreting cells appear to have nothing to do with the operation of Reproduction. We have seen that they do not even regenerate themselves; all their energies being, as it were, concentrated upon their own growth; and the successive production of new broods of them being provided for by other means. Throughout the organized creation, it appears to be necessary that the true act of Generation should be performed

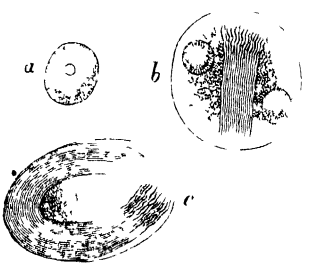
* The Synovial secretion is perhaps the only one which is poured into a closed sac.

† Secreting cells of Human Liver; *a*, nucleus; *b*, nucleolus; *c*, oil-particles.

by the re-union of the products of two distinct orders of cells (§ 780), the coalescence of which produces a germ that is the starting-point of a new organism;—thus differing from the act of Reproduction by *gemmation* or budding (§ 779), which essentially consists in an extension or outgrowth from the original organism, by the subdivision of cells in the manner already described (§ 211). Among the lowest Cellular Plants, in which every cell is apparently similar to the rest, this operation is effected by the 'conjugation' of *any* pair (as it would seem) of the cells which have been produced by multiplication from the original germ. But in all the higher organisms, both Vegetable and Animal, we find that certain cells are set-apart for this purpose; and that there is an obvious distinction between the 'germ-cells,' from within which the germ ultimately makes its appearance, and the 'sperm-cells,' which communicate to them a fertilizing influence. Still in the lower tribes, both of Plants and Animals, we find that 'sperm-cells' and 'germ-cells' are developed in the midst of the ordinary tissues of the body; and it is only as we ascend the scale, and find the principle of division of labour carried-out in other ways, that we meet, as in Man, with particular organs set apart for their evolution, and find these organs appropriate respectively to distinct individuals.

244. The spermatic cells of Man are developed within the tubuli of the Testicle; where they appear to hold exactly the same relation to the membranous walls of those tubuli, as do the secreting cells to the tubes and follicles of the proper Glands; being, in fact, the representatives of their epithelial cells (Fig. 34, *a*).

Fig. 34.*



Each of these developes in its interior a variable number of secondary cells, or 'vesicles of evolution;' and within every one of these is

* Formation of Spermatozoa within seminal cells; *a*, the original nucleated cell; *b*, the same enlarged, with the formation of the Spermatozoa in progress; *c*, the Spermatozoa nearly complete, but still enclosed within the cell.

produced a single thread-like body, dilated at one extremity, and possessed of a remarkable self-moving power, which is termed a Spermatozoon. Sometimes the vesicles of evolution remain enclosed within the parent-cell, until their spermatozoa have been completely developed, and have been set-free by their rupture (*b*); and thus, when they have all performed their office, the parent-cell contains nothing but a bundle of spermatozoa (*c*), whose dispersion takes place as soon as its cell-wall gives way.—From the very peculiar motion they possess, the Spermatozoa were long regarded as distinct and independent animalcules; it is now generally admitted, however, that they have no more claim to a distinct animal character, than have the ciliated epithelia of mucous membrane, which will likewise continue in movement when separated from the body. Similar bodies are formed by all the higher Cryptogamic Plants (such as Liverworts, Mosses, and Ferns); and it appears from late researches that their office, as in Animals, is to fertilize the contents of the 'germ-cells,' with which their self-moving power brings them into contact (§ 780). It is a curious fact that the seminal cells, in which the Spermatozoa are formed, are ejected from the gland in certain Crustacea, not only before they have burst and set-free their Spermatozoa, but even long before the development of the Spermatozoa in their interior is completed;—thus affording a complete demonstration of their independent vitality.

245. The 'germ-cells,' in like manner, are very commonly developed among the lower Animals as the epithelia of the tubes or follicles which constitute the ovary; but in Man and the higher Animals, the ovary is a solid organ, and the germ-cells are developed in its substance, lying in the midst of the dense fibrous tissue which forms its parenchyma. These germ-cells, which are known as 'ovisacs,' like the sperm-cells, develope secondary cells or *ova* in their interior; each ovisac, however, producing but a single ovum. The ovum, again, contains a tertiary cell (or rather, perhaps, a vesicular nucleus), the *germinal-vesicle*, whose contents appear to mingle with those of the sperm-cell in the act of fecundation, so that the fertilized germ is the result; the remaining contents of the ovum being the nutritive materials, at the expense of which this germ undergoes its first development (CHAP. XI.).

246. Thus we see that the several functions of Selection, Absorption, Assimilation, Respiration, Secretion, and Reproduction, are performed by the agency of cells in the Animal as in the Vegetable kingdom,—in the complex Human organism, as in the humblest Cryptogamic Plant: the chief difference being, that in the latter there is a greater division of labour, different groups of cells being appropriated to different functions in the general economy, whilst the history of their own processes of nutrition and decay is everywhere essentially the same. Thus we have seen that the

Absorbent cells, at the extremities of the intestinal or placental villi, select and draw into themselves, as the materials of their own growth, certain substances in their neighbourhood; which are still as much external to the tissues of the body, as are the fluids surrounding the roots of plants. Having come to their full term of life, they give up their contents to the absorbent vessels, which carry them into the general current of the circulation, where they are mingled with the fluid previously assimilated,—the blood. Whilst passing through the vessels, they are subjected to the action of the various cells (all of which we have seen to be successive phases of the same type) which float in the circulating current; and by these they seem to be gradually *assimilated*, or converted into a substance of a more directly organizable character. The special function of the red corpuscles peculiar to Vertebrated animals, though not yet accurately known, seems intimately connected with the process of *Respiration*. Next we have various groups of cells, external to the vessels, on the free surfaces of the body; whose office it is to draw from the blood certain materials, which are destined for *Secretion* or separation from it; either for the sake of preserving that fluid in its requisite purity, or for answering some other purpose in the system. These cells grow at the expense of the substances which they draw into themselves from the blood; and on their dissolution, they cast-forth their contents on the free surfaces communicating with the exterior of the body, to which they are in time conveyed. And, lastly, we have a special set of *Generative* cells, destined in the one sex to prepare the germs of new beings, and in the other to elaborate a product essential to their fertilization.

247. The cells which are thus the active instruments of the Organic functions, are usually produced and succeed one another with a rapidity proportional to the energy of those functions, though the causes which influence their growth and decay are not always evident. Thus it is certain that, *cæteris paribus*, the rate of production of the Secreting cells depends upon the abundance of the materials supplied by the circulating current, which they are destined to eliminate from it. But this is by no means the sole condition of their development; for, as we shall see hereafter, these materials may accumulate unduly in the blood, through the insufficient activity of the cells which are destined to separate them; whilst, on the other hand, the presence of certain substances in the blood appears to accelerate their production. Of these stimuli, Mercury is one of the most powerful; and we have continual opportunities of witnessing its effects, in giving an increased activity to the secreting actions. There is probably not a gland in the body, which is not in some degree influenced by its presence in the blood; but the liver, the kidneys, the salivary glands, and the glandulæ of the intestinal canal, appear to be those

most affected by its stimulating powers.—The action of the glands, in other words the development of the secreting cells, appears to be influenced by mental emotions; being sometimes accelerated, and sometimes retarded, through their agency. This is especially the case in regard to the secretion of Milk, Tears, Saliva, and Gastric juice. It seems probable that the influence thus manifested is partly exerted through the capillary circulation, which is known to be powerfully affected by mental emotions, as in the acts of blushing and erection; and that the increased production of the secretion is immediately due to the increased flow of blood to the gland. But there are other phenomena which show that the development and actions of the secreting cells are more directly influenced by the nervous system; these will be hereafter considered (CHAP. IX.).

5. *Of Cells connected together as permanent constituents of the Tissues.*

248. We now pass-on to consider those Cells which enter as component elements into the solid and permanent fabric of the body, and which do not take so active a part in its vital operations. These we shall find to be usually more or less closely connected together, either by a *general enveloping membrane*, or by an *intercellular substance*, which is interposed between their walls, and holds them together by its adhesive properties.

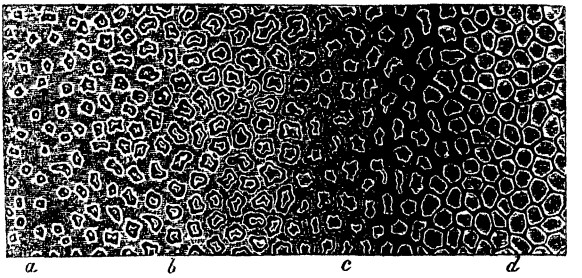
249. The presence of a general enveloping membrane (where it is not a secondary formation) appears to depend upon the persistence of the original cell-walls; which, instead of liquefying or thinning-away, when distended by the multiplication of cells in their interior, are thickened or strengthened by additional nutrition. Such is perhaps the case with the sacculi in which the cells of Adipose tissue (§ 257) are often found clustered together; but this condition is usually much more obvious in many tumours, whose development depends upon an abnormal process of growth.

250. Where such enveloping membranes are wanting, we frequently find the component cells of the permanent tissues of Animals (like those of the higher plants) held together by an *intercellular* substance; which generally presents no distinct traces of organization; and which usually consists of Gelatine, or of a substance allied to it in composition. The proportion of this substance to the cells may vary in different cases; and very different characters may thus be presented by a tissue made-up of the same elements. Thus the succeeding figure (35) represents a portion of one of the animal layers included between the calcareous laminæ of a bivalve shell; in which we see on the one side a number of nuclei or incipient cells, scattered through a bed of homogeneous intercellular substance, and bearing but a very small proportion to it;

whilst the opposite end exhibits a set of polygonal cells, in close contact with each other, the intercellular substance being only represented by the thick dark lines which mark the boundaries of the cells, and which are rather thicker at the angles of the latter. Between these two extremes, we observe every stage of transition.

251. The presence of a very large amount of intercellular substance, through which minute cells are scattered at considerable intervals (Fig. 35, *a*), is characteristic of various forms of Cartilage;

Fig. 35.*

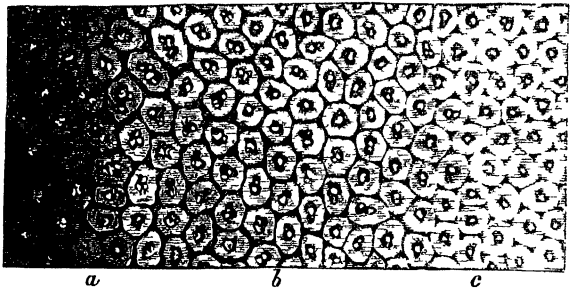


and more particularly of that soft semi-cartilaginous structure, of which the Jelly-fish are for the most part composed. In other forms of cartilage, we find the cells more developed, and in closer proximity to each other, the proportion of the intercellular substance being at the same time diminished (as seen at *b* and *c*, Fig. 35); but it is not often, save in embryonic structures, that we find the cells in such close proximity, and the intercellular substance so nearly wanting as at *d*. Such examples do occasionally present themselves, however, even in the soft tissues. Thus the *chorda dorsalis*, which replaces the vertebral column in the lowest Fishes, and of which the analogue is found in the embryoes of the higher Vertebrata, is made-up of a structure of this kind (Fig. 17). The true Skin, in the Short Sun-fish, is replaced by a similar layer of cellular tissue, which extends over the whole body, varying in thickness from one-fourth of an inch to six inches. And in the Lancelet (a little fish which is destitute of so many of the characters of a Vertebrated animal, that its right to a place in that division has been doubted), a considerable portion of the fabric is composed of a similar parenchyma.

* Portion of Shell-membrane, showing the origin of cells in the midst of horny intercellular substance;—*a*, nuclei; *b*, incipient cells, *c*, the same further advanced, but separated by intercellular substance; *d*, the cells become polygonal by mutual pressure.

252. It often happens, however, that the process of cell formation is checked, before the cells have been distinctly differentiated from the blastema in which they originated, such an imperfect *cellulation* being analogous to that imperfect *fibrillation*, to which reference has already been made (§ 178) And this seems to be the explanation of many appearances, which were formerly explained upon the hypothesis that cells which had once been completely formed, afterwards coalesced by the absorption or deliquescence of their parietes The appearances which have to be accounted for, are such as are represented in Fig 36 At *a*, the nucleated cells

Fig 36 *



are very distinct, and are separated by a large quantity of intercellular substance At *b*, they approach each other more closely, the amount of intercellular substance being less, the widest intervals are seen at the angles of the cells At *c*, the approximation is much closer, and the cell walls are scarcely distinguishable at the points where they come into immediate contact Proceeding further, we observe that the partitions are much less complete, so that the cellular character of the membrane is chiefly indicated by the bright nuclei which are regularly dispersed through it, and by the triangular dark spots, which show the remains of the intercellular substance at the angles where three cells join each other The indications of cell boundaries are often still more indistinct than they are shown to be in this figure so that, if it were not for the evidence afforded by the transition stages here represented, it would be difficult to show that they had any reference to the process of cellulation

253 Structures of the foregoing kind not unfrequently become

* Portion of Shell membrane showing the gradual coalescence of distinct cells —at *a* the cells separated by intercellular substance, at *b*, the partitions are thinner, and at *c*, they almost disappear

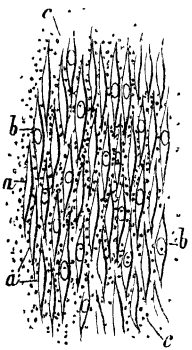
consolidated by the deposition of calcareous salts in their organic basis. Such a consolidation may take-place in a mass of blastema, before it shows any indication either of fibrillation or cellulation; as is certainly the case in the formation of the shells of many Mollusca. In other shells, the process of cellulation seems to have begun, sections of the shell giving indications of it not less distinct than those shown in Fig. 36; yet when the lime is removed by maceration in acid, no distinctly-cellular residuum is left, which seems to show that the differentiation had not proceeded far enough to separate the cell-walls either from the cell-contents or from the intercellular substance. In other shells, however (as in *Pinna*, § 281), the process of cell-formation has gone-on to completion, and the carbonate of lime is deposited in the interior of the cells, whilst their walls are strengthened by a condensed intercellular substance; so that, when a portion of such a shell is macerated in dilute-acid, a distinctly-cellular residuum is left.—In one layer of the egg-shell, as also in the scales of many fishes, ovoidal deposits of calcareous matter are found, as in the second form of shell-structure just described, without any distinct investing membrane; and these are probably deposited in 'vacuoles' which form in the plasma preparatory to its cellulation, which process is checked at that stage. On the other hand, the formation of the peculiar calcareous network of which the shell of the *Echinus* (§ 278) is composed, appears to be best accounted-for by supposing that after such 'vacuolation' has taken place, the intervening blastema is consolidated by calcareous deposit, the spaces which it encloses remaining empty. Such consolidation of the intercellular substance, after the complete development of cells, is seen in the formation of the first osseous tissue from cartilage (§ 301); and after the cartilage-cells have disappeared from the areolæ, the network that remains (which, being destitute of lacunæ and canaliculi, is quite homogeneous in its texture) bears no distant resemblance to that of the Echinus-shell. It is subsequently almost entirely removed, however, to be replaced by true Bone, which is formed on a very different plan.—In various abnormal growths, bony-looking deposits are occasionally met-with, which are found on minute examination to be calcified masses of cells; in other instances, however, they seem to be formed by the calcification of fibrous tissue.

254. Where the production of a continuous tube is required, this is formed by the *coalescence* of cells arranged in linear series. Such is unquestionably the origin of those long straight open ducts, through which the sap of Plants rises in the stem; and it seems probable that the network of anastomosing vessels, through which the elaborated sap finds its way to the various parts of the vegetable fabric(§ 543), is formed, in like manner, by the coalescence of cells, arranged obliquely and transversely in regard to one another. In

like manner, the capillary Blood-vessels of Animals are usually believed to originate in rows of cells, the cavities of which have run together by the obliteration of the transverse partitions; as the persistent nuclei of such cells may be occasionally brought into view in the walls of the capillaries. And the same has been supposed to be the origin of the tubular fibres of Muscular and Nervous tissue, which contain the elements characteristic of those tissues; these elements,—the fibrillæ of muscle, and the granular pith of the nerve-tube,—looking like the secondary products of parent-cells, which seem to remain as their investing tubuli, in the walls of which the original nuclei are often to be seen (§§ 338 and 388). The results of recent researches, however, render it doubtful whether such is really the origin of Muscular and Nervous fibres; which would rather seem to originate directly in a conversion of the formative blastema, than to pass through the condition of cells.

255. Without any such coalescence, the original cells may undergo marked alterations of form; and this quite independently of any pressure to which they may be subject. Thus the pigment-cells, as already mentioned (§ 229), frequently exhibit a curious *stellate* form; arising from the development of radiating prolongations, which are put-forth from the original spheroid. A form which is frequently assumed by the cells that are developed in fibrinous or plastic exudations, and which is also met-with in the cells of tumours, both malignant (or Cancerous) and non-malignant, is that which has received the designation of *fusiform* or spindle-like, from its prolonged shape and pointed extremities. The various stages of transition, which may be observed between the simple rounded cell and the fusiform cell, have been shown in Fig. 9; and it is there seen that, when the transformation has gone to its utmost extent, the nucleus of the cell is no longer visible, so that it bears a close resemblance to a simple fibre. Such cells are found amongst the simple fibrous tissues; and, in the opinion of many, they give origin to them.—The appearance of tissue, composed of fusiform cells, is shown in fig. 37; this is seldom met-with as a permanent part of the normal fabric; but it is a frequent product of morbid action.

Fig. 37.*



* Fusiform tissue of plastic exudations;—*a*, fusiform bodies without nuclei; *b*, nucleated fusiform cells: *c*, granular intercellular substance.

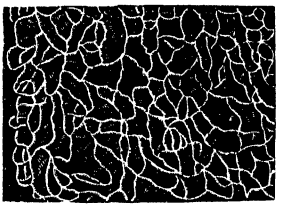
256. We now proceed with the description of the various tissues in the Human body, which are composed of cells united or transformed in the foregoing manner; and we shall commence with *Adipose* or *Fatty* tissue, which may be considered as a sort of link, connecting the permanent tissues with those which are more actively concerned in the processes of Nutrition, Secretion, &c.

257. The Adipose tissue is composed of isolated cells (Fig. 38) which have the power of appropriating fatty matter from the blood, precisely in the same manner as the secreting cells appropriate the elements of bile, milk, &c. These cells are sometimes dispersed in the interspaces of the Areolar tissue; whilst in other cases they are aggregated in distinct masses,—constituting the proper Adipose tissue. In the former case, they are held in their places by fibres that traverse the areolæ in different directions; whilst in the latter, each small cluster of fat-cells is included in a common envelope, on the exterior of which the blood-vessels ramify; and these sacculi are held-together by areolar tissue. We are thus probably to regard each fatty mass in the light of a gland, or assemblage of secreting cells, penetrated by blood-vessels, and bound-together by fibrous tissue; but instead of open (which appears to be having its follicles closed the early condition of the follicles of *all* glands, § 238): and consequently retaining its secretion within itself, instead of pouring it forth into a channel for excretion.

Fig. 38.*



Fig. 39.†



258. The individual fat-cells always present a nearly spherical or spheroidal form; sometimes, however, when they are closely pressed-together, they become somewhat polyhedral, from the flattening of their walls against each other. Their intervals are traversed by a minute net-work of blood-vessels (Fig. 39), from which they derive their secretion; and it is probably by the constant moistening of their walls with a *watery* fluid,

* Areolar and Adipose tissue;—*a*, *a*, fat-cells; *b*, *b*, fibres of areolar tissue.
† Capillary net-work around Fat-cells.

that their contents are retained without the least transudation, although they are quite fluid at the temperature of the living body. If the watery fluid of the cell-walls of a mass of Fat be allowed to dry-up, and it be kept at a temperature of 100°, the escape of the contained oily matter soon becomes perceptible.—By this provision, the fatty matter is altogether prevented from escaping from the cells of the living tissues, through gravitation or pressure; and as it is not itself liable to undergo change when secluded from the air, it may remain stored-up, apparently unaltered, for an almost unlimited period.

259. The consistency, as well as the Chemical constitution, of the fatty matter contained in the Adipose cells, varies in different animals, according to the relative proportions of three component substances which may be distinguished in it,—Stearine, Margarine, and Oleine. The two former are solid when isolated, and the latter is fluid; but at the ordinary temperature of the warm-blooded animal, they are dissolved in it. Of these, *Stearine* is the most solid; and it is most largely present, therefore, in the hardest fatty matter, such as mutton-suet. It is crystalline like spermaceti; it is not at all greasy between the fingers, and it melts at 143°. It is insoluble in water, and in cold alcohol and ether: but it dissolves in boiling alcohol or ether, crystallizing as it cools. The substance termed *Margarine* exists along with stearine in most fats, but it is the principal solid constituent of Human fat, and also of Olive oil. It corresponds with Stearine in many of its properties, and is nearly allied to it in composition; but it is much more soluble in alcohol and ether, and it melts at 118°. On the other hand, *Oleine* when pure remains fluid at the zero of Fahrenheit's thermometer; and it is soluble in cold ether, from which it can only be separated by the evaporation of the latter. It exists in small quantity in the various solid fats; but it constitutes the great mass of the liquid fixed oils. The tendency of these to solidification by cold, depends upon the proportion of stearine or margarine they may contain.

260. All these substances are neutral compounds formed by the union of *Stearic*, *Margaric*, and *Oleic* acids, respectively, with a base termed *Glycerine;* this base may be obtained from any fatty matter, by treating it with an alkali, which unites with the acid and forms a soap, setting-free the Glycerine. They contain no Nitrogen; and their proportion of Oxygen is extremely small, in comparison with their amount of Carbon and Hydrogen: thus Stearine has 142 Carbon and 141 Hydrogen, to 17 Oxygen: and in the other substances the proportions are similar. The fatty bodies appear to be mutually convertible; thus margaric acid may be procured from stearic acid, by subjecting it to dry distillation; and there is ample evidence that animals supplied with one of them may produce the others from it.

261. Since these Fatty matters are abundantly supplied by the Vegetable kingdom, and are found to exist largely in substances which were not previously supposed to contain them, it is not requisite to suppose that Animals usually elaborate them by any transforming process from the elements of their ordinary food. The mode in which they are taken into the blood, and the uses to which they are subservient, will be hereafter investigated: but it may be here remarked, that the portion separated from the circulating fluid to form the Adipose tissue, is only that which can be spared from the other purposes to which the fatty matters have to be applied. Hence the production of this tissue depends in part upon the amount of Fatty matter taken-in as food; but this is not entirely the case, as some have maintained; for there is sufficient evidence that animals *may* produce fatty matter by a process of chemical transformation, from the starch or sugar of their food, when there is an unusual deficiency of it in their aliment.

262. The development of Adipose tissue in the body appears to answer several distinct purposes. It fills-up interstices, and forms a kind of pad or cushion for the support of moveable parts; and so necessary does it seem for this purpose, that even in cases of great emaciation some fat is always found to remain, especially at the base of the heart around the origin of the great vessels, and in the orbit of the eye. It also assists in the retention of the animal temperature by its non-conducting power; and we accordingly find a thick layer of it in those warm-blooded mammals that inhabit the seas,—either immediately beneath their skin, or incorporated with its substance. Its most important use, however, is to serve as a reservoir of combustible matter, at the expense of which the respiration may be maintained when other materials are deficient; thus we find that the respiration of hybernating animals is kept-up, during the period when they cease taking food (§ 121), by the consumption of the store of fat which was laid-up in their bodies previously to their passing into that state; and it is also to be noticed that herbivorous animals, whose food is scanty during the winter, usually exhibit a strong tendency to such an accumulation during the latter part of the summer, when their food is most rich and abundant, so as to supply the increased demand created by the low external temperature of the winter season. Other circumstances being the same, it appears that the length of time during which a warm-blooded animal can live without food, depends upon the quantity of fat in its body; for the rapid lowering of its temperature, which is the immediate cause of its death (§ 117), takes-place as soon as the whole of this store has been exhausted.

263. In order that it may be applied to the maintenance of the animal heat, the fatty matters must be received back into the blood; and although we have no certain knowledge of the mode in which this is accomplished, yet it may be surmised to be as follows.

The Blood normally contains a certain amount of fatty matter, held in solution by combination with its alkali; and should this be exhausted by the combustive process, the circulating current will draw into itself a fresh supply from the interior of the fat-cells;—it having been shown by Matteucci that oleaginous particles will pass through animal membranes by endosmose, to diffuse themselves through an aqueous liquid, provided the latter be alkaline.

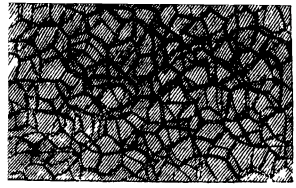
264. In the simpler forms of *Cartilage* we have an example of a tissue of remarkable permanence, composed entirely of cells scattered through an intercellular substance. This substance has received the distinguishing appellation of *Chondrin*, which marks it as the solidifying ingredient of Cartilage (§ 177). All the Cartilages of the fœtus,—those which are to be converted into bone, as well as those which are to remain unossified,—are composed of it; and yet, as soon as the process of Ossification commences, the chondrin is replaced by Gelatin, which is the sole organic constituent of the animal basis of bones. The permanent cartilages, however, still contain only Chondrin; but if accidental bony deposits should take-place in them (as frequently happens in old persons, especially in the cartilages of the ribs), the Chondrin gives place to Gelatin. This change of composition is coincident, as we shall hereafter see, with a complete change in texture; the real basis of bone not being Cartilage (as commonly imagined), but consisting of a substance much more nearly allied to the white fibrous tissue.—It is only in the pure *cellular* cartilages, in which the intercellular substance presents no trace of organization, that true Chondrin occurs. The *fibro*-cartilages (§ 269), in which the intercellular substance has the characters of the White fibrous tissue, yield gelatin on boiling, in the manner of the ligaments and tendons; whilst those which contain much of the Yellow or elastic tissue, undergo very little change by boiling, and only yield, after several days, a small quantity of an extract which does not form a jelly, but which has the other chemical properties of Chondrin.

265. Besides the organic compounds already described, most Cartilages contain a certain amount of mineral matter, which forms an ash when they are calcined. This ash contains a large proportion of carbonate and sulphate of soda, together with carbonate of lime, and a small quantity of phosphate of lime; as age advances, the proportion of the soluble compounds diminishes, and the phosphate of lime predominates. This is especially the case in the costal cartilages, which almost invariably become converted into a semi-ossified substance, in old persons; and it is remarkable that, even before they have themselves become thus condensed, they unite by ossific matter when they have undergone fracture.

266. When a pure Cellular Cartilage is examined microscopically, its cells are seen to lie, sometimes singly, and sometimes in clusters

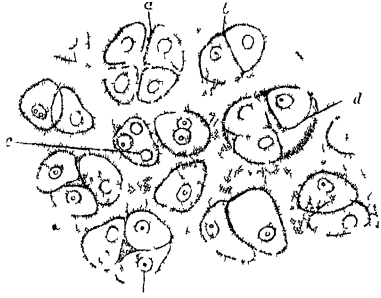
of two, three, or four, in cavities excavated in the intercellular substance These occur at very variable distances, for in some instances they are packed together as closely as the cells of a vegetable parenchyma (Fig 40), whilst in others the principal mass is composed of intercellular substance, through which the cells are interspersed at wide intervals From the various appearances which may be observed in the same cartilage at different stages of its growth, it would appear that the component cells multiply by the *dividing* process already described (§ 212), that they then separate from one another, each of them producing for itself an envelope of intercellular substance, and that, by the repetition of the same process, the number of cells in the cartilage may be indefinitely multiplied

Fig 40 *



267 Various stages of this history are shown in the accompanying figure (Fig 41), which is taken from a section of the cartila-

Fig 41 †



ginous branchial ray of the larva or tadpole of the *Rana esculenta*, or Edible Frog In the centre of the figure are shown three separate cells, which have evidently been at one time in closer proximity

* Cartilage of Mouse's ear

† Section of Branchial cartilage of Tadpole —*a*, group of four cells separating from each other *b* pair of cells in apposition, *c*, *c*, nuclei of cartilage cells, *d*, cavity containing three cells

with each other. In one of these cells, the nucleus is seen to be developing two new cells in its interior; and a continuation of this process would give rise to the appearance shown at *b*, where two cells are shown in close contact, being evidently the offspring of the same parent. Now if each of these cells in like manner developes two others within itself, a cluster of four will be developed, as shown at *a;* and after a time, intercellular substance being accumulated around each, their walls will separate, and they will acquire the character of distinct cells. It would seem as if one of the first pair of cells occasionally developes another pair in its interior, whilst the other (from some unknown cause) does not at once proceed to do so; and thus only three cartilage-cells, instead of four, are clustered together in the cavity, as seen at *d*.

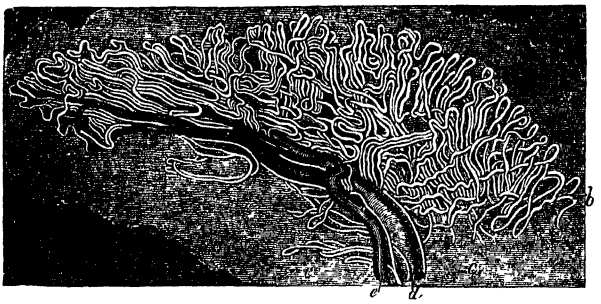
268. The primitive *cellular* organization now described, is retained in some Cartilages through the whole duration of their existence. This is the case, for example, in most of the articular cartilages of joints; in the cartilaginous portion of the septum narium, in the cartilages of the alæ and point of the nose, in the semilunar cartilages of the eyelids; in the cartilages of the larynx (with the exception of the epiglottis), the cartilages of the trachea and bronchial tubes, the cartilages of the ribs, and the ensiform cartilage of the sternum. When partial ossific deposits take place, it is usually in the substance of *cellular*, rather than in that of *fibrous* cartilage.

269. When the intercellular substance, instead of being homogeneous, has a fibrous character, the tissue called *Fibro-Cartilage* is produced; and this may be either elastic or non-elastic, according as the yellow or the white form of fibrous structure prevails. In some instances, the fibrous structure is so predominant over the cellular, that the tissue has rather the character of a ligament than of a cartilage. The white fibrous structure is seen in all those cartilages, which unite the bones by synchondrosis, and which are destined not merely to sustain pressure, but also to resist tension. This is the case especially in the substances which intervene between the vertebræ, and which connect the bones of the pelvis; these in adult Man are destitute of cartilage-corpuscles, except in and near their centres; but in the lower Vertebrata, and in the early condition of the higher, the fibrous structure is confined to the exterior, and the whole interior is occupied by the ordinary cartilage-corpuscles. The yellow-fibrous or reticulated structure is best seen in the epiglottis, and in the concha of the ear; in the former of these, scarcely any trace of cartilage-corpuscles remains; and in the latter, the cellular structure is only to be met-with towards the tip.

270. We have seen that the elements of the cellular tissues hitherto described, do not come into direct contact with the blood-vessels. The Epidermic and Epithelial cells are separated from

them by the continuous layer of basement-membrane, which forms the surface of the true skin, of the mucous membranes, of the glandular follicles produced from them, &c. (§ 241). In like manner, the cells of adipose tissue are formed within membranous bags; around which the blood-vessels form a minute network. The cells of Cartilage are not nourished in any more direct manner; and are sometimes at a considerable distance from the nearest vessels. It is certain that the substance of the permanent cellular Cartilages is *not* permeated, in a state of health, even by the minutest nutrient vessels; none such being brought into view under the highest magnifying power. They are, however, surrounded by vessels (Fig. 42),

Fig. 42.*



which form large *ampullæ* or varicose dilatations at their edges, or spread over their surfaces; and it is by the fluid which is drawn from them by the Cartilage-cells, that the latter are nourished. The nutrition of a mass of Cartilage thus seems to bear a strong resemblance to that of the thick fleshy Sea-weeds, which are in like manner composed entirely of cells, with intercellular substance disposed between them in greater or smaller amount. The cells in nearest proximity to the nutrient fluid, draw from it the requisite materials, and transmit these to the cells in the interior of the mass, receiving a fresh supply in their turn from the source in their own neighbourhood. When the Articular or other cellular Cartilages are inflamed, however, we find vessels passing into their substance;

* Vessels situated between the attached Synovial membrane, and the Articular Cartilage, at the point where the ligamentum teres is inserted in the head of the os femoris of the human subject, between the third and fourth months of fœtal life:—*a*, the surface of the articular cartilage; *b*, the vessels between the articular cartilage and the synovial membrane; *c*, the surface to which the ligamentum teres was attached; *d*, the vein; *e*, the artery.

but these vessels are formed in an entirely new tissue, which is the product of the inflammatory process, and cannot be said to belong to the Cartilage itself.

271. The temporary Cartilages, which have a like cellular structure, but which are destined to undergo metamorphosis into Bone, are equally destitute of vessels when their mass is small; but if their thickness exceed an eighth of an inch, they are permeated by canals for the transmission of vessels. Still these vessels do not leave the canals, which are everywhere lined by a prolongation of the investing perichondrium; and they continue to be as much outside the actual substance of the Cartilage, as if they were distributed on its external surface alone.

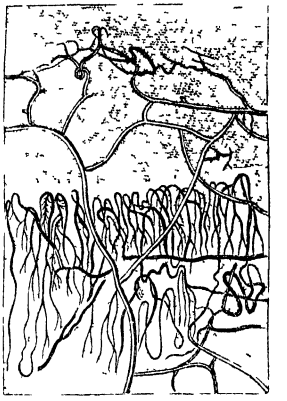
272. The Fibro-Cartilages, formed as it were by the intermingling of two distinct elementary structures, have a degree of vascularity proportioned to the amount of the fibrous tissue which they contain; but these vessels do not penetrate the cellular portions, where such are distinct from the mixed structure.

273. The Cartilaginous tissue appears to be more removed than almost any other in the body, from the general tide of nutritive action. Its properties are simply of a physical character; and they are not impaired for a long time after the death of the tissue, its tendency to decomposition being very slight, so long as it is exposed to ordinary temperatures. It is protected by its toughness and elasticity from those mechanical injuries, to which softer or more brittle tissues are liable; and consequently it has little need of any active power of reparation. When loss of substance occurs as a result of disease or accident, this seems never to be repaired by real cartilaginous substance; but the space is filled-up by a fibrous tissue developed from the reparative blastema (§ 213). It is in this tissue that the new vessels are found, which have been erroneously supposed to penetrate the cartilage when it becomes inflamed; the fact being, that the vessels are restricted to the 'false membrane' formed in the inflammatory process, which takes the place of the cartilaginous tissue that has disappeared in consequence of imperfect nutrition or degeneration.

274. The *Cornea* of the Eye bears a superficial resemblance to Cartilage; but it corresponds rather with fibrous membranes in its elementary structure. Besides its anterior or conjunctival layer, which consists of epithelium, and its posterior layer of cells constituting the epithelium of the aqueous humour, the Cornea has been shown by Mr. Bowman to consist of three layers, of which the anterior and the posterior (which are very thin) have some of the characters of the yellow elastic tissue, whilst the middle one, which forms its principal thickness, is composed of white fibres interlaced together in such a manner as to form numerous lamellæ, the interspaces or areolæ having the form of tubes regularly arranged and constricted at intervals, so as not to be unlike rows of cartila-

cells, for which in fact they have been mistaken.—Two sets of vessels, a superficial and a deep-seated, surround the margin of the cornea. The former (Fig. 43, A) belong rather to the Conjunctival membrane, which forms the outer layer of the cornea; and they are prolonged to the distance of 1-8th or half a line from its margin, then returning as veins. The latter (B) do not pass into the true Cornea, but terminate in dilatations from which veins arise, just where it becomes continuous with the sclerotic. In diseased conditions of the Cornea, however, both sets of vessels extend themselves through it. Notwithstanding the absence of vessels in the healthy condition of the corneal tissue, incised wounds of its substance commonly heal very readily, as is well seen after the operation for Cataract; but there is a danger in carrying the incision around a large proportion of its margin, lest the tissue should be too much cut-off from the supply of nutriment afforded by the ampullæ of the vessels that surround it.

Fig 43.*



275. The *Crystalline Lens* of the Eye approaches Cartilage, in its structure and mode of nutrition, more nearly than any other tissue. It may be separated into numerous laminæ, which are composed of fibres that lock into one another by their delicately-toothed margins; and each of these fibres appears to be made-up of a series of cells, linearly arranged, which coalesce at an early period. The lens is not permeated by blood-vessels, at least after it has been completely formed; these being confined to the capsule. During the early part of fœtal life, and in inflammatory conditions of the Capsular membrane, both its anterior and its posterior portions are distinctly vascular, the anterior, which is at that time semi-opaque, being known as the *membrana pupillaris;* but during the latter half of fœtal life, the vessels of the anterior capsule gradually retreat from its centre towards its periphery, and the

* Nutrient Vessels of the Cornea.—A, superficial vessels belonging to the Conjunctival membrane, and continued over the margin of the Cornea, B, vessels of the Sclerotic returning at the margin of the Cornea.

membrane itself clears-up and becomes transparent; and at last, only the posterior half of the Capsule has vessels distributed upon its surface. It has been shown by optical experiments devised for the purpose, that a moderate vascularity of the posterior capsule does not interfere with distinct vision; whilst if the anterior capsule were traversed by vessels, the picture on the retina would be no longer clear.—The substance of which the lens is composed, is that to which the name *Globulin* is now restricted by Prof. Lehmann (§ 221); it is nearly allied to the albumen of the blood.

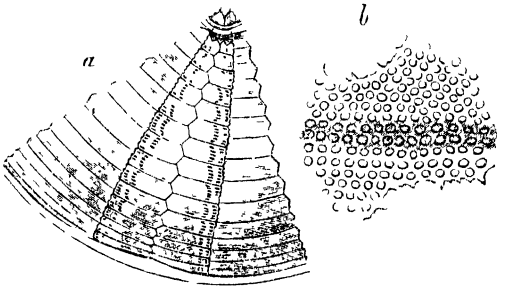
276. The *Vitreous* body, which fills the greater part of the globe of the eye, also seems to possess a cellular structure; the cells containing a fluid, which is little else than water holding in solution a small quantity of albumen and saline matter; and the membrane which forms their walls being so pellucid as to be scarcely distinguishable. Indeed the cellular character of this substance is chiefly inferred from the fact, that when its capsule or enveloping membrane is punctured, even in several places, the contained fluid does not speedily drain-away,—as it would do if it were merely contained in the interstices of an areolar tissue. The blood-vessels which traverse the Vitreous body do not send branches into its substance; and it must derive its nutriment from those which are distributed minutely upon its general envelope, and probably also from the large plexiform vessels of the ciliary processes of the Choroid coat.

277. Before proceeding to describe the structure of *Bone*, to which it seems natural to pass-on from Cartilage, it will be useful to advert to the modes in which the tissues of Invertebrated animals are consolidated by deposits of solid matter, in order that they may afford the requisite support and protection, without that interstitial growth which is peculiar to the skeletons of the Vertebrated classes. —Commencing with the Polypifera, or Coral-forming animals, we observe that their strong axes or sheaths are destined only to give *support* to their softer structures, and that the parts once consolidated undergo no subsequent change. It was formerly imagined, that the stony Corals were 'built-up' by the animals which form them, somewhat in the same manner as a Bee constructs its cell. But it is now fully demonstrated, that the calcareous matter (which here consists solely of the *Carbonate* of Lime) is combined with the living tissue, and that the most solid mass of Coral thus has an organized basis. The proportion of earthy to animal matter, however, is so great in these structures, that very little, if any, nutrient changes can take place in their tissue, when once it has become consolidated. Such changes are not, however, required. The substance thus developed by the attractive power of the soft gelatinous tissues, which draw into themselves the small quantity of calcareous matter dissolved in the surrounding water, is so little disposed to undergo change, that it will maintain its solidity for

centuries; and even when acted-on by water or by heat, it does not undergo disintegration, for its calcareous particles arrange themselves in a new method, and become converted into a solid crystalline rock. Such rocks, the product of the metamorphosis of ancient Coral-formations, make-up a large proportion of the external crust of the earth. The solid stem or sheath, once consolidated, appears to undergo no further change in the living Coral-structure; for its increase takes place, not by *interstitial* but by *superficial* deposit, that is, not by the diffusion of new matter through its whole substance, separating from each other the parts formerly deposited, but by the mere addition of particles to its surface and extremities. In this manner, the growth of a solid Coral-structure may proceed to an enormous extent; the surface at which the consolidating action is going-on, being the only part *alive*, that is, exhibiting any vital change; and all the rest of the mass being henceforth perfectly inert.

278. In the class of Echinodermata, which includes the Star-fish, Sea-Urchin, &c., we find the calcareous structure presenting a very elaborate organization; as an example of this, we shall select the shell of the *Echinus*, commonly known as the 'sea-egg.' This shell is made-up of a number of plates, more or less regularly hexagonal, and fitted-together so as completely to enclose the animal, except at two points, one of which is left open for the mouth, the other for the anus. On the surface of these plates are little tubercles for the articulation of the spines, which serve as instruments of defence and of locomotion. The substance of the shell and of the spines is exactly alike; being a sort of *arcolar tissue*, consolidated by the deposition of calcareous matter, and having an innumerable series

Fig. 11*



* Portion of the shell of the *Echinus*, showing at *a* the constituent plates, and at *b* the calcified arcolar tissue of which they are composed.

of interspaces or minute cancelli, freely communicating with each other. The arrangement of this calcareous net-work in the spines is most varied and elaborate; and causes thin sections of them to be among the most beautiful of all microscopic objects. The external and internal surface of each plate, in the shell of the living Echinus, is covered with a membrane from which its nutrition is derived; this membrane dips-down into the spaces between the adjacent plates, but it does not penetrate the substance of the plates themselves, nor does it transmit vessels to their interior. A similar membrane covers and encircles the spines; and it also connects these with the shell, being continuous with the membrane that envelopes the latter. Thus each plate and spine is itself completely *extra-vascular;* but it is enclosed in a soft membrane, which furnishes (whether by vessels or otherwise, has not yet been ascertained) the elements of its nutrition.

279. But we do not here find any evidence of *interstitial* growth; nor is there any reason why such should be required. For the tissue of which it is composed, although of such extreme delicacy, is of great permanence, and does not exhibit the slightest tendency to decay, however long it is preserved; so that, when once consolidated, it appears to undergo no further change in the living animal. The growth of the animal, however, requires a corresponding enlargement of its enveloping shell; and this is provided-for by the simple process of superficial deposit, through the subdivision of the whole shell into component plates. For by the addition of new matter *at the edge of each plate*, by the consolidation of a portion of the soft membrane that intervenes between the adjacent plates, the whole shell is enlarged, without losing its globular form. At the same time it is strengthened in a corresponding degree, by the consolidation of the soft tissue at the *surface* of each plate. And, in like manner, the spines are enlarged and lengthened by the progressive formation of new layers, each on the exterior of the preceding, so that their transverse section exhibits a number of concentric rings, like those of an Exogenous tree.—Thus even in the growth of this complex and elaborate structure, we recognize the principle of superficial deposit, which we shall find to be universal amongst the hard parts of the Invertebrata: notwithstanding that, at first sight, it would have appeared impossible to provide on this plan for the gradual enlargement of a globular shell, completely enclosing the animal, and therefore required to keep pace with the latter in its rate of increase.

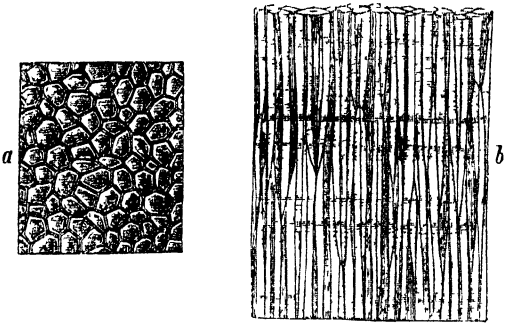
280. Among the Mollusca, we find the body sometimes altogether destitute of solid organs of support, protection, or locomotion,—as is the case, for example, in the Slug: and the movements are feeble and the habits inert, the muscles having no fixed points for their attachment, and acting without any of the advantages of leverage. In other cases, we find the body more or less completely protected

by a Shell; which is sufficiently large in some instances to cover the body completely, whilst in others it affords only a partial investment. The plan on which this shell is formed, however, is very different from that which has just been described; being much less complex. The *Univalve* shells, or those formed in one piece, are always of a conical form; the cone being sometimes simple, as in the Limpet; in other cases being spirally coiled, as in the Snail. Now the base of this cone is open; and through this, the animal can project its moveable parts. When its increasing size requires additional accommodation, it is obvious that an addition to the large end of the cone will increase its diameter and its length at the same time; so as to afford the required space, without any alteration in the form or dimensions of the older and smaller portions of the cone. This last, indeed, is frequently quitted by the animal, and remains empty; being sometimes separated from the later portions, by one or more partitions thrown-across by the animal,—as is seen especially in the Nautilus and other 'chambered' shells. Besides the new matter added to the mouth of the shell, a thin layer is usually formed over its whole interior surface; so that the lining of the new part is continuous with that of the old.—In the *Bivalve* shells, which usually cover the upper and lower surfaces of the animal they protect, we trace this mode of increase without any difficulty; especially in such shells as that of the Oyster, in which the successive laminæ remain distinct. Each lamina is *interior* to the preceding, being formed on the living surface of the animal; but it also projects beyond it, so as to enlarge the capacity of the shell; and as the separation of the valves affords free exit to those parts of the animal which are capable of being projected beyond the shell, there is obviously no need of any other provision to maintain the shell in its natural form.—Thus in the shells of the Mollusca, increase takes place at the surfaces and edges only.

281. The proportions of the Organic and the Mineral components of Shell, differ considerably in the various tribes. The former is sometimes present in such small amount that it can scarcely be detected; and the condition of the calcareous matter then obviously approaches that of a crystalline deposit. But in other instances, the animal basis is very obvious; remaining as a thick consistent membrane, after all the calcareous matter has been dissolved-away by an acid. This membrane is formed of an aggregation of cells arranged with great regularity (Fig. 45, *a*); the cavities of which are filled with carbonate of lime in a crystalline state. The form of the cells approaches the hexagonal; their diameter varies in different shells from 1-100th to 1-2800th of an inch; their thickness also is extremely variable, even in different parts of the same shell. Thus we sometimes meet with a lamina of such tenuity, as not to measure 1-100th of an inch in thickness, whilst in other instances, a single layer may have a thickness of half an

inch, or even (in certain large fossil species) of an inch or more. In this case, the cells, instead of being thin flat scales like the tesselated-epithelium (§ 233), are long prisms, somewhat like the cells of the cylinder-epithelium, with their walls flattened

Fig. 45.*



against each other. The appearance which is then presented by a vertical section of them, is represented in Fig. 45, *b*. The long prismatic cells are there seen to be marked by delicate transverse striæ, and these, taken in connection with other indications, appear to show that every such prism is in reality formed by the coalescence of a pile of flat cells, resembling those which are seen in the very thin laminæ just described; so that the thickness of the layer depends upon the number of the cellular laminæ which have coalesced to form its component prisms. This character is of interest, as representing on a magnified scale a corresponding appearance in the *Enamel* of human Teeth, which we shall presently find to be formed upon the very same plan (§ 318).

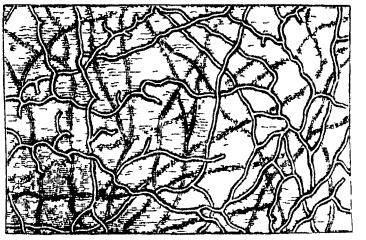
282. We are to regard this kind of shell-substance, therefore, as formed by the secreting action of the epithelial cells covering the 'mantle' of the animal,—which membrane, though it answers in position to the skin, has the soft spongy, glandular character of a mucous membrane. These cells draw calcareous matter into their cavities, as a part of their own process of growth; this matter being supplied from the fluids of the vascular surface beneath. Now when these calcigerous cells are separated by intercellular substance, they remain distinct through the whole of their lives, and they form by their cohesion a tenacious membrane, that retains

* Prismatic cellular structure of shell of *Pinna*.—*a*, surface of lamina; *b*, vertical section.

its consistency after the removal of the calcareous matter. But this is only the case in certain groups of shells, chiefly belonging to the bivalve division. When the intercellular substance is wanting, and the cells lie in close contact, their partitions are often rendered indistinct by their extreme tenuity; whilst not unfrequently the formative blastema appears to have become calcified, before its cellulation had advanced to such a degree as to establish a distinct separation between the cells, so that the calcified substance exhibits few or no traces of cellular organization (§ 252).

283. In some of these last cases, we find the almost-homogeneous substance traversed by a series of tubuli, not arranged, however, in any very definite direction, but forming an irregular net-work (Fig. 46). These tubes vary in size from 1-2000th to

Fig. 46 *



1-20,000th of an inch; but their general diameter, in the shells in which they most abound, is 1-4500th of an inch. In the larger tubuli, something of a bead-like character may occasionally be seen; as if their interior were occupied by rounded granules arranged in a linear direction. Although it might be supposed that these tubuli are destined to convey nutrient fluid into the substance of the shell, yet there is no evidence that such is the fact; and on the contrary there is ample evidence, that even in shells most copiously traversed by them, no processes of interstitial growth or renewal take place. The *permanent* character of the substance of all Shells, when once it is fully formed, is as remarkable as that of Coral; and as the adaptation of their size to that of the animals to which they belong, is entirely effected by additions to their surfaces and edges, no interstitial deposit can have a share in producing it.

284. Among the Articulated classes, we still find that the skeleton is altogether external, and belongs therefore to the cutaneous system; but it is formed upon a very different plan from the shells of the Mollusca, being closely fitted to the body,

* Tubular shell-structure, from *Anomia*

and enveloping every part of it; consequently it must increase in capacity, with the advancing growth of the contained structures. Moreover it is destined not merely to afford support and protection to these, but to serve for the attachment of the muscles by which the body and limbs are moved; and the hard envelopes of the latter serve, like the bones of the Vertebrata, as levers by which the motor powers of the muscles are more advantageously employed. Again, the hard envelopes of the body and limbs are not formed of distinct plates, like those of the Echinus-shell; but are only divided by sutures at the joints, for the purpose of permitting the requisite freedom of motion. It might have been thought that here, if anywhere, a process of interstitial growth would have existed, to adapt the capacity of the envelopes to the dimensions of the contained parts, as the latter increase with the growth of the animal; but true to the general principle, that epidermic structures are not only extra-vascular but undergo no change when they are once fully formed, we find that the hard envelopes of Articulated animals are thrown-off, or exuviated, when the contained parts require an increase of room; and that a new covering is formed from their surface, adapted to their enlarged dimensions.

285. This is well known to occur at certain intervals in Crabs, Lobsters, and other Crustacea; which thus exuviate not merely the outer shell, with the continuation of the epidermis over the eyes, but also its internal reflexion, which forms the lining of the œsophagus and stomach, and the tendinous plates by which the muscles are attached to the lining of the shell. A similar moulting may be observed to occur in some of the minute Entomostracous Crustacea of our pools, every two or three days, even after the animals seem to be full grown. During the early growth of Insects, Spiders, Centipedes, &c., a similar moult is frequently repeated at short intervals; but after these animals have attained their full growth, which is the case with Insects at their last change, no further moulting takes place, the necessity for it having ceased.—This moulting is precisely analogous to the exfoliation and new formation of the Epidermis, in Man and most other Vertebrata; differing from it only in this, that the latter is constantly taking place to a small extent, whilst the former is completely effected at certain intervals, and then ceases. We have examples of a periodical complete moult in Vertebrata, however, among Serpents and Frogs.

286. The structure of the hard envelopes of Articulated animals corresponds with that of the Epidermis and its appendages in Man. The firm casings of Beetles, for example, are formed of layers of epidermic cells, united together, and having their cavities filled by a horny secretion. The densest structure is found in the calcareous shells of the Crustacea; which consists of a substance precisely ana-

logous to the *Dentine* of Teeth (§ 311); covered on the exterior with a layer of polygonal pigment-cells. The calcareous matter consists chiefly of carbonate of lime; but traces of the phosphate are also found. The animal basis has a firm consistent structure, resembling that of teeth. A thin vertical section shows tubuli running nearly parallel, but with occasional undulations, from the internal surface towards the external: the manner in which these are formed, is probably the same with that in which the Dentinal substance originates (§ 313).

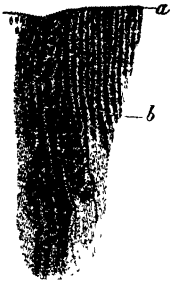
287. Now the condition of the osseous skeleton of Vertebrated animals is altogether different. Its purpose is still only mechanical; its sole use being, to afford support and protection to the softer textures, and to supply a set of inflexible levers, by the action of the muscles upon which, motion may be given to the different parts of the fabric. But it forms a part of the internal substance of their bodies; and as these grow in *every* part, and not merely by addition to this or that portion, so must the Bones also, in order to keep pace with the rest of the structure. Hence we find them so constructed, that the processes of *interstitial* deposition may be continually going-on in their fabric, as in that of the softer tissues; and the changes in their substance do not cease, even when they have acquired their full size. The subsequent continuance of these changes appears destined, not so much to repair any *waste* occasioned by decomposition,—for this must be very trifling in a tissue of such solidity,—as to keep the fabric in a condition, in which it may repair the injuries in its substance occasioned by accident or disease. The degree of this reparative power is proportional, as we shall presently see, to the activity of the normal changes which are continually taking place in the bone; and is thus much greater in youth than in middle life, and greater in the vigour of manhood than in old age.

288. The structure of Bones is well adapted to demonstrate the distinction between the tissues themselves, and those subsidiary parts by which they are connected with the rest of the fabric. We have seen that Cartilage is essentially *non-vascular;* that is, even when it exists in a considerable mass, it is not traversed by vessels, but is nourished by absorption from the fluids contained in the vessels distributed on its exterior. Now every mass of Bone is traversed by vessels; nevertheless these do not penetrate its ultimate substance, and may be easily separated from it, leaving the bone itself as it was. In fact, as Prof. Goodsir observes, "a well macerated bone is one of the most easily made, and, at the same time, one of the most curious anatomical preparations. It is a perfect example of a texture completely isolated; the vessels, nerves, membranes, and fat, are all separated, and nothing is left but the non-vascular osseous substance." Precisely the same may be said of the substance of a Tooth, from which the

vascular lining of the pulp-cavity has been removed; for it then possesses neither vessels, nerves, nor lymphatics; and yet, as we shall presently see, it has a highly-organized structure, peculiar to itself.

289. The general characters of Osseous texture vary according to the shape of the Bone, and the part of it examined. Thus in the *long* bones, we find the shaft pierced by a central canal, which runs continuously from one extremity to the other; and the hollow cylinder which surrounds this, is very compact in its structure. On the other hand, the dilated ends of the bone are not penetrated by the large central canal; nor are they composed of solid osseous substance. They are made-up of *cancellated* structure, as it is termed; that is, of osseous lamellæ and fibres interwoven together (like those of areolar tissue, on a larger scale) so as to form a multitude of minute chambers or *cancelli* (Fig. 47), freely communicating with each other, and with the cavity of the shaft; whilst the whole is capped with a thin layer of solid bone. Again, in the thin flat bones, as the scapula, we find the two surfaces composed of solid osseous texture, with more or less of cancellated structure interposed between the layers. And in the thicker flat bones, as the parietal, frontal, &c., this cancellated structure becomes very distinct, and forms the diploë; this, however, is sometimes deficient, leaving a cavity analogous to the canal of the long bones: whilst the plates which form the surfaces of the bone (the external and internal tables of the skull) resemble in their thickness and solidity, as well as in the intimate structure presently to be described, the shaft or hollow cylinder of those bones. Finally, we frequently meet (especially in the Ethmoid and Sphenoid bones) with thin lamellæ of osseous substance, resembling those which elsewhere form the boundaries of the cancelli; these consist of but one layer of bony matter, and show none of the varieties previously adverted-to; they are not penetrated by vessels, but are nourished only by their surfaces; and they consequently exhibit to us the elements of the osseous structure in their simplest form. It will be desirable, therefore, to commence with the description of these.

Fig. 47.*

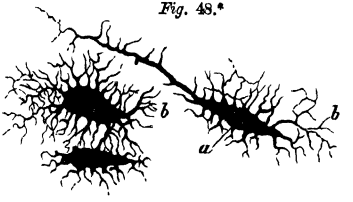


290. When a thin natural lamella of this kind is examined, it is found to be chiefly made-up of a substance which is nearly homo-

* Extremity of Os femoris, showing cancellated structure:—*a*, thin layer of bone, in contact with the articular cartilage; *b*, cancelli.

geneous, sometimes exhibiting indistinct traces of a fibrous arrangement; this, however, may be generally resolved by prolonged boiling, into an assemblage of minute granules, varying in size from 1-6000th to 1-14,000th of an inch, which are more or less angular in shape, and seem to cohere by the medium of some second substance, which is dissolved by the boiling. They are composed of Calcareous salts, apparently in chemical union with the Gelatine that forms the basis of the osseous substance. In the midst of this granular substance, a number of dark spots are to be observed, the form of which is very peculiar. In their general outline, they are usually somewhat oval; but they send forth numerous radiating prolongations of extreme minuteness, which may be frequently traced to a considerable distance (Fig. 48). These spots, now

Fig. 48.*



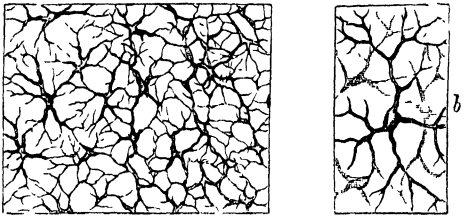
known as the *osseous lacunæ* (but formerly termed the *Purkinjean corpuscles*, after the name of their discoverer), are highly characteristic of the true bony structure, being never deficient in the minutest parts of the bones of the higher animals, although those of Fishes are frequently destitute of them. They were formerly supposed, from their dark appearance, to be opake, and to consist of aggregations of calcareous matter which would not transmit the light: but it is now quite certain that they are open spaces, and that the radiating prolongations from them, which are far smaller than the minutest capillary vessel, are *canaliculi* or delicate tubes. Of these canaliculi, some may be seen to interlace freely with each other, whilst others proceed towards the surface of the bony lamella; and thus a system of passages, not by any means wide enough to admit the blood-corpuscles, but capable of transmitting the fluid elements of the blood or matters selected from them, is established through the whole substance of the lamella.

291. The lacunæ of Human bone have an average length of 1-1800th of an inch; and they are usually about half as wide, and one-third as thick. The diameter of the canaliculi is from 1-12,000th to 1-20,000th of an inch. Their size and form differ greatly, how-

* Lacunæ of Osseous substance, magnified 500 diameters:—*a*, central cavity; *b*, its ramifications.

ever, in the different classes of Vertebrata; so that it is usually possible to refer a mere fragment of bone to its proper group, by an examination of its minute structure. The succeeding figure (Fig. 49)

Fig. 49.*



represents the arrangement of these lacunæ and canaliculi in the bony scale of a Fish (the *Lepidosteus*), which is almost the only existing representative of a large class of bony-scaled Fishes that formerly tenanted the seas. Its lacunæ will be seen to differ greatly in form from those of Human bone; and the canaliculi which proceed from them are much fewer in number.—The purpose of this penetration of the osseous texture by such a complicated apparatus of tubuli, can scarcely be anything else than the maintenance of its vitality by the continual percolation of nutrient fluid, drawn into the system of lacunæ and canaliculi from the neighbouring blood-vessels. Thus the nutrition of the ultimate osseous texture, though carried-on upon the same general plan with that of Cartilage, differs in this;—that there is a provision in Bone for the ready transmission of nutrient matter through its texture, by means of minute channels, which does not exist in Cartilage; a difference obviously required by the greater solidity of the substance of the former, which does not allow of the diffused imbibition that is permitted by the softer and moister nature of the latter. We shall presently find that these channels are only formed at a late stage of the development of bone, when the remaining tissue has acquired its completest consolidation.

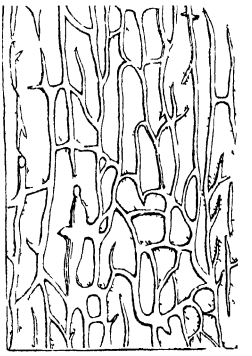
292. Now, as already remarked, the simple structure just described is found, not merely in the delicate plates which form the thinnest part of certain bones in Man, but also in those lamellæ which form the walls of the *cancelli* of the larger and thicker bones. Every one of these lamellæ repeats, in fact, the same history. The cancelli are lined by a membrane derived from that of the cavity of

* Section of the bony scale of *Lepidosteus*:—*a*, showing the regular distribution of the lacunæ and of the connecting canaliculi; *b*, small portion more highly magnified.

the shaft, over which blood-vessels are minutely distributed; and by the materials drawn from these, each lamella is nourished through its system of lacunæ and radiating canaliculi. The cancelli, at the time of their formation in the fœtal bone, are entirely filled with cells, which appear (as will be presently explained) to be the descendants of the cells of the original cartilage; but in the adult bone they are for the most part occupied by fat-cells, like those which constitute the 'marrow' (§ 294). The vessels of the cancellated structure at the extremities of the long bones, are derived from those of the medullary cavity, which is penetrated by large trunks from the exterior; and in the flat bones, they form a system of their own, connected with the vessels of the exterior by several smaller trunks.

293. The solid osseous texture which forms the cylindrical shafts of the long bones and the thick external plates of the denser flat bones, is not cut-off from nutritive action in the degree in which it might seem to be; for it is penetrated by a series of large canals, termed the *Haversian* (after Clopton Havers, their discoverer), which form a net-work in its interior, and which serve for the transmission of blood-vessels through its substance (Fig. 50). These canals, in the long bones, run for the most part in a direction parallel to the central cavity; and they communicate with this, with the external surface, with the cancelli, and with each other, by frequent transverse branches; so that the whole system forms an irregular network, pervading every part of the solid texture, and adapted for the establishment of vascular communications throughout. The diameter of the Haversian canals varies from 1-2500th of an inch to 1-200th or more; their average diameter may be stated at about 1-500th of an inch. They are lined by a membrane, which is continuous with that of the external surface, and which carries this inwards (so to speak) to form the lining membrane of the central cavity, and of the cancelli; and the cavity of the tube encloses a single twig of an artery or vein. Thus we may consider the whole Osseous texture as inclosed in a membranous bag, on which blood-vessels are

Fig. 50 *



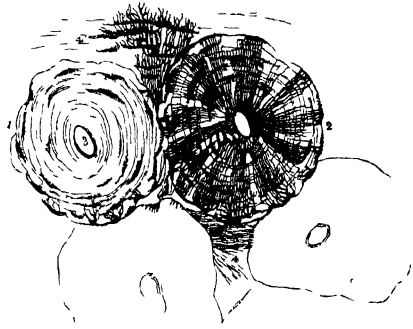
* Vertical section of tibia, showing the net-work of Haversian canals.

minutely distributed, and which is so carried into the bone by involutions and prolongations, that no part of the latter is ever far removed from a vascular surface.

294. In the adult bone, the cells which fill the remaining cavity of these canals, secrete fatty matter; this is particularly evident in the case of the central cavity, which may be considered as an immensely-dilated Haversian canal, wherein they constitute the *medulla* or 'marrow.' It does not appear that this takes any active part in the nutrition of the bone; indeed in the bones of Birds, the shaft is entirely hollow, and air is admitted into it from the lungs, so that its lining membrane is rendered subservient to the aeration of the blood.

295. The arrangement of the elementary parts of the osseous substance around the Haversian canals, is very interesting and beautiful. When a transverse section of a long bone is made, the open orifices of the longitudinal canals present themselves at intervals, sometimes connected by a transverse canal where the section happens to traverse this. Around these orifices, we see the osseous matter arranged in the form of cylinders, which appear to be marked by concentric circles (Fig. 51, 1, 2). Now when one of

Fig. 51.*



* Minute structure of Bone, as shown in a thin section cut transversely to the direction of the Haversian canals:—1. one of the Haversian canals surrounded by its concentric lamellæ; the lacunæ are seen between the lamellæ, but the radiating tubuli are omitted; 2 an Haversian canal with its concentric laminæ, lacunæ, and radiating tubuli; 3. the area of one of the canals; 4, 4. intervening lamellæ; between these lamellæ at the upper part of the figure, several very long lacunæ with their tubuli are seen. In the lower part of the figure, the outlines of two other canals are given, in order to show their form and mode of arrangement in the entire bone.

these circles is minutely examined, it is found to be made-up of a series of lacunæ analogous to those already described; these, however, are seldom or never so continuous as to form a complete circle. The long sides of the lacunæ are directed, the one towards the Haversian canal (3) in the centre, the other towards the circular row next beyond it. And when the course of the canaliculi is traced, it is found that these converge on the inner side towards the central canal, inosculating with those of the series next within, whilst those of the outer side pass outwards in a radiating or diverging direction, to inosculate with those of the series next external. Thus a complete communication is formed, by means of this system of radiating canaliculi and intervening lacunæ, between the central canal, and the outermost cylindrical lamella of bony matter; and each of these lamellæ derives its nourishment from the vessels of the central canal, through the lamellæ which intervene between itself and the vascular membrane lining that tube.

296. Thus every one of the Haversian canals is the centre of a cylindrical *ossicle;* which is complete in itself, as far as its elementary structure is concerned; and which has no dependence on, or connexion with, other similar ossicles. These are arranged, however, side by side, like sticks in a faggot; they are bound together by a thin cylinder of bone on the exterior of all, which derives its nourishment from the periosteum or enveloping membrane; in like manner, the hollow bundle is lined by a similar cylinder, which surrounds the great medullary cavity, and is nourished by its vascular membranes; and the spaces that here and there intervene between the ossicles, are filled-up with laminæ (4), which are portions of some former Haversian system of which the larger part has undergone removal by absorption (§ 305). By this arrangement, the whole structure becomes possessed of great density and solidity.—The structure of the outer and inner tables of the skull, and of other thick solid layers of bone, is precisely similar; except that the Haversian canals have no such definite directions, and form an irregular network.

297. Thus we see that each of the lamellæ of bone surrounding an Haversian canal or bounding the cancelli, may be regarded as a repetition of the simple bony lamina (§ 292) which draws its nourishment direct from the vascular membrane covering its surface, by means of its system of lacunæ and canaliculi. The membrane lining the Haversian canals, cancelli, and central medullary cavity, is an internal prolongation of that which clothes the exterior; just as the mucous membranes, with their extensions into glandular structures, are internal prolongations of the true skin. Every Haversian canal and every cancellus are repetitions of each other in all essential particulars; their form alone being different. The central medullary canal is but an enlarged Haversian canal or cancellus. And the

whole cylindrical shaft is a collection of 'ossicles,' each of which is a miniature representation of itself, being a hollow cylinder, with a central vascular cavity.

298. The principal features of the Chemical constitution of Bone are easily made evident. After all the accessory parts have been removed, and nothing remains but the real osseous texture, this may be separated by simple processes into its two grand constituents,—the animal basis, and the calcareous matter. The latter may be entirely removed, by maceration of the bone in dilute Muriatic or Nitric acid; and a substance of cartilaginous appearance is then left, which, when submitted to the action of boiling water for a short time, is almost entirely dissolved-away, the solution forming a dense jelly on cooling. The same substance, Gelatine, may be obtained by long boiling under pressure, from previously-unaltered bone; and the calcareous matter is then left in a friable condition. By submitting a bone to a heat sufficient to decompose the animal matter, without dissipating any of the earthy particles, we may obtain the whole calcareous matter *in situ;* but the slightest violence is sufficient to disintegrate it. The bones of persons long buried are often found in this condition; their form and position being retained until they are exposed to the air or are a little shaken, when they crumble to dust.—The proportion of the earthy matter of Bones to the animal basis may be differently stated; according as we include in our estimate of the latter, the contents of the medullary cavity, the Haversian canals, and the cancelli; or confine ourselves to that portion only of the animal matter, which is united with the calcareous element in the proper osseous tissue. According to the experiments of Dr. Stark,* the relative amount of the two elements, in the latter estimate, is subject to very little variation, either in the different classes of animals, or in the same species at different ages; the animal matter composing about one-third, or $33\frac{1}{3}$ per cent.; and the mineral matter two-thirds, or $66\frac{2}{3}$ per cent. The degree of hardness of bone does not altogether depend, therefore, on the proportion of earthy matter they may contain; for the flexible, semi-transparent, easily-divided bones of Fish contain no larger an amount of animal matter than the ivory-like leg-bones of the Deer or Sheep. The usual analyses of Bone, however, have been made upon the former kind of estimate; and they show that the proportion of the earthy matter to the *whole* of the animal substance contained in bone, varies much in different animals, in the same animal in different ages, and even in different parts of the same skeleton. The reason of this will be apparent, when the history of the growth of Bone has been explained; since there is a gradual filling-up of all the cavities at first occupied by fat-cells, vessels, &c., which does not cease with adult age, but continues during the whole

* Edinburgh Medical and Surgical Journal, April, 1845.

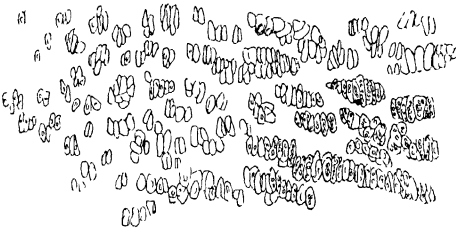
of life. In this manner, the bones of old persons acquire a high degree of solidity, but they become brittle in proportion to their hardness. From the same cause, the more solid bones contain a larger proportion of bone-earth than those of a spongy or cancellated texture; the temporal bone, for example, containing 63½ per cent., whilst the scapula possesses only 54 per cent. In the former of these bones, the proportion is nearly the same as that which exists in pure osseous tissue, the amount of the remaining tissues which it includes being very small, on account of the solidity of the bone: but the latter contains in its cancelli a large quantity of blood-vessels, fat-cells, &c., which swell the proportion of the animal matter from 33⅓ to 46 per cent.

299. The Lime of bones is for the most part in the state of Phosphate, especially among the higher animals; the remainder is a Carbonate. In Human bones, the proportion of the latter seems to be about one-sixth or one-seventh of the whole amount of bone-earth. In the bones of the lower animals, however, the proportion of Carbonate is greater; and it is curious that in callus, exostosis, and other irregular osseous formations in the higher animals, the proportion of the Carbonate should be much greater than in sound bone. In caries, however, the proportion of the Carbonate is less than usual. The composition of the Phosphate of Lime in Bones, is somewhat peculiar; eight equivalents of the base being united with three of the acid. According to Professor Graham, it is to be regarded as a compound of two tribasic phosphates; one atom of the *neutral* phosphate (in which one proportional of the acid is united with two of lime and one of water), being united with two proportionals of the *alkaline* phosphate (in which one part of acid is united with three of the base), together with an atom of water, which is driven-off by calcination. Besides these components, a small quantity of Fluoride of calcium is present in Bone.—Other mineral substances, such as phosphate of magnesia, oxides of iron and manganese, and chloride of sodium, are found in bones in small amount.

300. The first development of Bone is usually preceded by the formation of a Cartilaginous structure, which occupies the place afterwards to be taken by the bone; and it is commonly considered that the bone is formed by the calcification of the cartilage-substance. This, however, does not appear to be the case, as will be presently shown; and it would probably be more correct to say that the cartilage is superseded by bone. Moreover, bone is frequently developed in the substance of Fibrous membranes; and the structure produced by this *intra-membranous* ossification cannot be distinguished from that which is generated by the *intra-cartilaginous*.—We shall commence the history of the development of Bone, with the period in which its condition resembles that of the permanent Cartilages. As already mentioned, there is no essential

difference between the temporary and permanent cartilages, in regard to their ultimate structure; the former, however, are more commonly traversed by vessels, especially when their mass is considerable. Still, these vessels do not pass at once from the exterior of the cartilage into its substance; but they are conveyed inwards along canals, which are lined by an extension of the perichondrium or investing membrane, and which may thus be regarded as so many involutions of the outer surface of the cartilage. These canals are especially developed at certain points, which are to be the centres of the ossifying process; of these *puncta ossificationis*, we usually find one in the centre of the shaft of a long bone, and one in each of its epiphyses; in the flat bones there is one in the middle of the surface, and one in each of the principal processes. Up to a late stage of the ossifying process, the parts which contain distinct centres are not connected by bony union, so that they fall apart by maceration; and even when they should normally unite, they sometimes remain separate,—as in the case of the Frontal bone, in which we frequently meet with a continuation of the sagittal suture down the middle, dividing it into two equal halves, which have originated in two distinct centres of ossification. It is interesting to remark that, in the two lower classes of Vertebrata,—Fishes and Reptiles,—we find the several parts of the osseous system presenting, in a permanent form, many of the conditions which are transitory in the higher; thus the different portions of each vertebra, the body, lateral arches, spinous and transverse processes, &c., which have their distinct centres of ossification, but which early unite in Man, remain permanently distinct in the lower Fishes; the division of the frontal bone, just adverted-to, is constant amongst Fishes and

Fig. 52.*

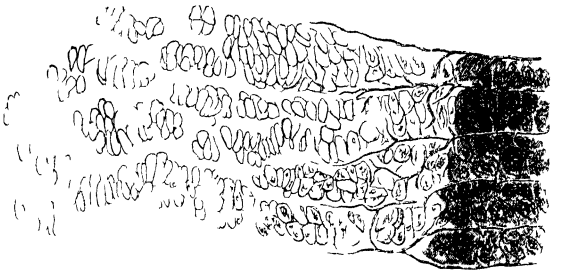


* Section of Cartilage, near the seat of Ossification; each single cell having given origin to four, five, or six cells, which form clusters. These clusters are larger towards the right of the figure, and their cells more numerous and larger; their long diameter being 1-1500th of an inch.

Reptiles; and in those classes we meet with a permanent separation of the parts of the occipital and temporal bones, which, being formed from distinct centres of ossification, are at first disconnected in the higher animals.

301. During the formation of the *punctum ossificationis*, and the spread of the vessels into the cartilaginous matrix, certain changes are taking place in the substance of the latter, preparatory to its conversion into bone. Instead of single isolated cells, or groups of two, three, or four, such as we have seen to be characteristic of ordinary Cartilage (§ 267), we find, as we approach the ossifying centre, clusters made-up of a larger number, which appear to be formed by a continuance of the same multiplying process as that already described (Fig. 52). And when we pass still nearer, we see that these clusters are composed of a yet greater number of cells, which are arranged in long rows, whose direction corresponds with the longitudinal axis of the bone, these clusters are still separated by intercellular substance, and it is in this that the ossific matter is first deposited (Fig. 53). Thus if we separate the carti-

Fig 53*



laginous and the osseous substances at this period, we find that the ends of the rows of cartilage-cells are received into deep narrow cups of bone, formed by the transformation of the intercellular substance between them. Immediately upon the ossifying surface, the nuclei, which were before closely compressed, separate con-

* The same Cartilage at the seat of Ossification, the clusters of cells are arranged in columns, the intercellular spaces between the columns being 1-3250th of an inch in breadth. To the right of the figure, osseous deposits are seen occupying the intercellular spaces, at first bounding the clusters laterally, then splitting them longitudinally and encircling each separate cell. The greater opacity of the right hand border is due to a threefold cause, the increase of osseous deposits, the opacity of the contents of the cells, and the multiplication of oil-globules.

siderably from one another, by the increase of material within the cells; and the nuclei themselves become larger and more transparent. These changes constitute the first stage of the process of ossification, which extends only to the calcification of the intercellular substance; in this stage there are no blood-vessels directly concerned. Of the bony lamellæ thus formed, some are speedily absorbed again, whilst others mark-out the boundaries of the cancelli and Haversian systems, which are afterwards to occupy a part of the space hitherto filled by the rows of cartilage-corpuscles (§ 304).

302. Up to this point, there is no essential difference in the accounts of those who have most carefully studied the process of ossification; but in regard to the history of its subsequent stages, there is much discrepancy; and this especially with respect to the origin of the bone-lacunæ, which some regard as metamorphosed cartilage-cells, others as the spaces originally occupied by their nuclei, whilst others do not regard them as in any way derived from the cartilage-cells, but consider them as a new formation. Much may doubtless be urged in favour of each view; the author's own observations incline him to the latter, and lead him to regard the lacunæ as *cells*, which, like the pigment-cells of Batrachia, &c., have sent out stellate prolongations that constitute the canaliculi. All stages of gradation may be traced, between simple rounded cavities,—whose correspondence in size with the cells that are scattered in the midst of the consolidating blastema leaves scarcely any doubt of their identity with these,—and the lenticular or spindle-shaped lacuna with numbers of canaliculi proceeding from it. These gradations are particularly well seen during the process of ossification; so that it seems probable that the radiating extension of the cells takes-place during the consolidation of the surrounding tissue.—It is an additional argument against the idea that the bone-lacunæ in any way originate from the cartilage-cells, that they are found to present exactly the same characters in bone which is developed in the substance of fibrous membrane (after the manner to be presently described), and in the formation of which, therefore, cartilage has had no participation.

303. Although, in a large proportion of the skeleton, the formation of Bone is preceded by that of cartilage, yet such is by no means invariably or necessarily the case; for the flat bones, such as the scapula and those forming the roof of the skull, have usually only a centre of cartilage, beyond which the ossifying process extends in membrane only. This membrane is chiefly composed of fibrous fasciculi, corresponding with those of the white fibrous tissues; but amongst these are seen numerous cells, some about the size of blood-disks, but others two or three times larger, containing granular matter; and a soft amorphous or faintly-granular matter is also found interposed amidst the fibres and cells. The process of ossification here seems essentially to consist in the consolidation of

the fibres by earthy matter; for the first bony deposit is seen as an irregular reticulation, very loose and open towards its edges, and there frequently presenting itself in the form of distinct spicules, which are continuous with fasciculi of fibres in the surrounding membrane. The limits of the calcifying deposit may be traced by the opaque and granular character of the parts affected by it; and it gradually extends itself, involving more and more of the surrounding membrane, until the foundation is laid for the entire bone. Everywhere the part most recently formed consists of a very open reticulation of fibro-calcareous spicules, whilst the older part is rendered harder and more compact by the increase in the number of these spicules. As the process advances, and the plate of bone thickens, a series of grooves or furrows, radiating from the ossifying centre, are found upon its surface; and these, by a further increase in thickness, occasioned by a deposit of ossific matter all around them, are gradually converted into closed canals (the Haversian), which contain blood-vessels, and are lined by processes of the investing membrane. The lacunæ and canaliculi seem to take their origin in the cells which are interspersed among the fibres; their prolongations extending themselves, and insinuating themselves through the spaces left between the interlacing fibres, whilst the process of calcification is going-on.

304. The first Osseous tissue which is formed by either of these processes, has an irregular *cancellated* structure, analogous to that which is found at the extremities of the long bones in adults. This is gradually modified by changes which essentially consist in absorption and new deposition; for the absorptive process first unites minute areolæ into larger ones, by removing their partitions; and it is upon their interior walls that new osseous lamellæ are now deposited, from materials supplied by the blastema they contain. It is by a process of this kind, that the central medullary cavity is first formed in the bones of young animals. At an early period, no such cavity exists, and its place is occupied by small cancelli; this is the permanent condition of the bones in most Reptiles. The cancelli gradually enlarge, however; and those within the shaft coalesce with one another until a continuous tube is formed, around which the cancelli are large, open, and irregular. At the same time, the diameter of the surrounding shaft is increasing by the process of interstitial growth just described; so that the size of the medullary cavity at last becomes greater than that of the whole shaft when its formation commenced. The aggregation of the osseous matter in a hollow cylinder, instead of a solid one, is the form most favourable to strength, as may be easily proved upon mechanical principles. The same arrangement is adopted in the arts, wherever it is desired to obtain the greatest strength with a limited amount of material.

305. The growth of Bones takes place by the addition of new

tissue to the part already formed; but this addition may take place in three modes,—namely, by the development of new bone in the *cartilage* yet remaining between the different centres of ossification; by the development of new bone in the *membrane* covering the surface; and by the interstitial formation of new layers within the Haversian canals and cancelli of the part already formed, by which the requisite solidity is given to it. Of the first process we have the most characteristic example in the increase in length of a long bone, by the ossification of the cartilage which intervenes between the shaft and the epiphyses, and which continues to grow, up to the time of the final union of these parts. Thus it was long since proved by the experiments of Hales and Hunter, that the growth of a long bone takes place chiefly towards the extremities; for they found that, when metallic substances were inserted in the shaft of a growing bone of a young animal, the distance between them was but little altered after a long interval, whilst the space between the extremities of the bone had greatly increased. And it seems that, at a later period, when the epiphyses have become completely united to the shaft, an elongation continues to take-place, by the slow ossification of the articular cartilage.—Again, the bone is progressively increased in thickness, by the gradual production of new osseous matter upon its surface; this production being effected by the conversion of the inner layer of the periosteum, the fibres of which are found to be continuous with those of the animal matrix of the surface of the bone.—And it is by the successive formation of new layers of osseous tissue, one within another, giving the appearance of concentric rings when the Haversian canals are cut across (Fig. 51), that the proportion of hard to soft parts in bone is gradually increased; the calibre of the Haversian canals being correspondingly diminished.—Even after the completion of the bone, however, interstitial changes are continually taking-place in its substance, as in that of the softer tissues; old Haversian systems being partially or entirely removed by absorption, and new ones being developed in their place.

306. The difference in the relations of the Osseous substance to the vascular net-work, at different ages,—accounting for the variations in the rapidity of its nutrition and reparation,—is well displayed in the effects of Madder. This substance has a peculiar affinity for Phosphate of Lime; so that when the latter is formed by precipitation in a fluid tinged with madder, it attracts colour to it in its descent, and falls to the bottom richly tinted. Now when animals are fed with this substance, it is found that their bones become tinged with it, the period required being in the inverse proportion to their age. Thus in very young animals a single day suffices to colour the entire skeleton, for in them there is no osseous matter far from the vascular surfaces; when sections are made, however, of the bones thus tinged, it is found that the colour

is confined to the immediate neighbourhood of the Haversian canals, each of which is encircled by a crimson ring. In full-grown animals, the bones are very slowly tinged; because the osseous texture is much more consolidated and less permeable to fluid than in earlier life; and because the vascular membrane lining the Haversian canals is removed further from the outer and older layers of osseous tissue which surround them, by the interposition of newer concentric layers, which diminish the diameter of the canals. In the bones of half-grown animals, a part of the bone is nearly in the perfect condition, while a part is new and easily coloured; so that the action of this substance enables us to distinguish the new from the old.

307. The Regeneration of Bone, after loss of its substance by disease or injury, is extremely complete; in fact there is no other structure of so complex a nature, which is capable of being so thoroughly repaired. Although the regenerative power appears to be so much less in Vertebrated animals than it is in the lower Invertebrata, yet it is probably not at all lower in reality; the new structures actually formed being as complex in the one case as in the other. It is nowhere, perhaps, more remarkably manifested, than in the re-formation of nearly an entire bone, when the original one has been lost by disease; all the attachments of muscles and ligaments, as well as the external form and internal structure, being ultimately found as complete in the new bone, as they originally were in that which it has replaced. Much discussion has taken-place, in regard to the degree in which the different membranous structures that surround bone and penetrate its substance, participate in its regeneration; some having supposed the periosteum to have the power of itself forming new bone, others attributing the same power to the membrane lining the medullary cavities. It appears certain, however, that new osseous tissue may be formed in a great variety of modes. It has been ascertained by Mr. Paget* that it may be produced through the intermediation of perfect fibrous tissue, either when this previously existed as such (as the periosteum or interosseous membrane), or when it has been newly formed by the fibrillation of the plastic fluid effused as the material for reparation.* The agency of the periosteum is seen in many cases of necrosis, in which that membrane has been completely detached from the dead shaft, and new bone has been generated from its interior. The ossification of a newly-produced fibrous membrane is believed by Mr. Paget to be the ordinary mode of reparation of fracture of the skull; and it takes-place in a manner essentially the same as that of the original intra-membranous development of bone. But new bone may also be formed, according to that most excellent observer, by ossification of the fibrous tissue in

* Lectures on Surgical Pathology, vol. i. p. 244.

its rudimental state (§ 193). In abnormal bone-growths, it sometimes appears as if the tissue had been formed by the ossification of cells; but more commonly the calcification takes-place in an earlier stage of tissue-production, that of the 'nucleated blastema,' in which a granular osseous deposit is seen, which gradually increases so as to form the lamellæ of a fine cancellous texture, at the same time enclosing the nuclei, which seem to occupy the places afterwards to be left as lacunæ. It is seldom that the reparation of bone takes-place through the intermediation of cartilage; though this is occasionally formed, rather, perhaps, in the lower animals than in the human subject.

308. In the reparation of Bone, after disease or injury, a plastic or organizable exudation is first poured-out from the neighbouring blood-vessels, and this forms a sort of bed or matrix, in which the subsequent processes take-place. At first, all new bone possesses a minutely cancellous structure, much like that of the fœtal bones in their first construction; but this gradually assimilates itself to the structure of the bones which it repairs, its outer portions acquiring a more compact laminated texture, while its interior substance acquires wider cancellous spaces, and a perfect medulla. When the shaft of a long bone of an animal has been fractured through, and the extremities have been brought evenly together, it is found that the new matter first ossified is that which occupies the *central* portion of the deposit, and which thus connects the medullary cavities of the broken ends, forming a kind of plug that enters each. This was termed by Dupuytren, by whom it was first distinctly described, the *provisional callus*. This is usually formed in the course of five or six weeks, or less in young subjects; but at that period the contiguous surfaces of the bone itself are not cemented by bony union; and the formation of the *permanent callus* occupies some months, during which the provisional callus is gradually absorbed, and the continuity of the medullary canal restored, in the same manner as it was at first established. The permanent callus has all the characters of true bone.—It seems to have been established by the observations of Mr. Paget, however, that these statements do not usually apply to the case of Man; in whom, when the limb is kept at rest, the union between the fractured ends is accomplished by ossification of the substance connecting them, without the intermediation of a provisional callus; this being only formed when the portions of the bone are kept in continual movement.

309. The most extensive reparation is seen, when the shaft of a long bone is destroyed by disease. If violent inflammation occur in its tissue, the *death* of the fabric is frequently the consequence,—apparently through the blocking-up of the canals with the products of the inflammatory action, and the consequent cessation of the supply of nutriment. It is not often that the whole thickness of

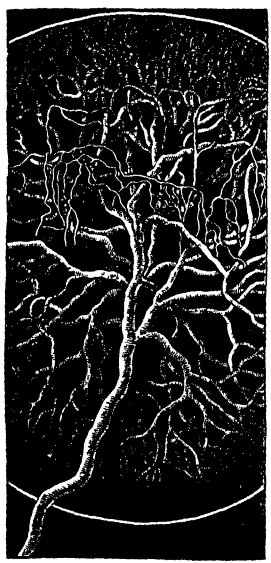
the bone becomes necrosed at once; more commonly this result is confined to its outer or its inner layers. When this is the case, the new formation takes-place from the part that remains sound; the external layers, which receive their vascular supply from the periosteum and from the Haversian canals continued inwards from it, throwing-out new matter on their interior, which is gradually converted into bone; whilst the internal layers, if *they* should be the parts remaining uninjured, do the same on their exterior, deriving their materials from the medullary membrane and its prolongations into their Haversian canals. But it sometimes happens that the whole shaft suffers necrosis; and as the medullary membrane and the entire system of Haversian canals have lost their vitality, reparation can then only take place from the periosteum, and from the living bone at the two extremities. This is consequently a very slow process; more especially as the epiphyses, having been originally formed as distinct parts from the shaft, do not seem able to contribute much to the regeneration of the latter.

310. We next proceed to the *Teeth*, which are organs of mechanical attrition, developed in the first part of the alimentary canal, for the purpose of comminuting the food conveyed into it. Their place of origin is altogether different from that of bone, as they commence in little papillary elevations of the mucous membrane covering the jaw; but the substance from which they are formed is the same primitive cellular tissue, as that in which Cartilage itself originates. We may best understand the structure and development of the Teeth in Man, by first inquiring into the characters presented by those of some of the lower animals, and the history of their evolution. In the fœtal Shark, the first appearance of the tooth is in the form of a minute papilla on the mucous membrane covering the jaws; the tissue of this papilla is composed of spherical cells, which are imbedded in a kind of gelatinous substance resembling that of incipient cartilage; whilst its exterior is composed of a dense, structureless, pellucid membrane. The cellular mass is not at first permeated by vessels; but a small arterial branch is distributed to each papilla, and spreads-out into a tuft of capillaries at its base (Fig. 54). The papilla gradually enlarges, by the formation of new cells at the part immediately adjacent to the blood-vessels, which supply the material requisite for their development; and when it has acquired its full size, the process of *calcification* commences, by which it is converted into Dentine,—the substance most characteristic of teeth.

311. This *Dentine*, which in the Elephant's tusk is known as Ivory, is a firm substance, in which mineral matter predominates to a greater extent than in bone; but which still has a definite animal basis, that retains its form when the calcareous matter has been removed by maceration in acid. In every 100 parts, the

animal matter forms about 28; and of the mineral portion, phosphate of lime constitutes about 64½ parts, carbonate of lime 5½ parts, and phosphate of magnesia and soda, with chloride of sodium, about 2½ parts. When it is fractured, it seems to possess a fibrous appearance; the fibres radiating from the centre of the tooth towards its circumference. But when a thin section of it is submitted to the microscope, it is seen that this fibrous appearance is

Fig. 54.*

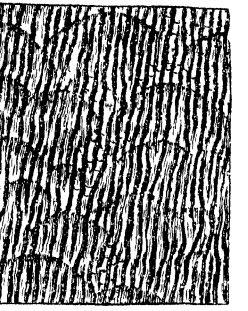


due to a peculiar structure in the dentine, which the unaided eye cannot discover. The dentinal substance is itself very transparent; but it is traversed by minute tubuli, which appear as dark lines, generally in very close approximation, running from the internal portion of the tooth towards the surface, and exhibiting numerous minute undulations, and sometimes more decided curvatures, in their course (Fig. 55). They occasionally divide into two branches,

* Vessels of Dental Papilla.

which continue to run at a little distance from one another in the same direction; and they also frequently give-off small lateral branches, which again send off smaller ones. In some animals, the tubuli may be traced at their extremities into minute cells or cavities, analogous to the lacunæ of bone; and the lateral branchlets occasionally terminate in such cavities, which are called the intertubular cells. The diameter of the tubuli at their largest part, averages 1-10,000th of an inch; their smallest branches are immeasurably fine. It is impossible that even the largest of them can receive blood, as their diameter is far less than that of the blood-discs; but it is probable that, like the canaliculi of bone, they may absorb nutrient matter from the vascular surface, with which their internal extremities are in relation.

Fig. 55.*



312. In the Teeth of Man and of most Mammalia, we find the central portion hollow; and lined, in the living tooth, by a vascular membrane. This cavity (Fig. 56, *e*), with its vascular wall, is analogous to an enlarged cancellus or Haversian canal of Bone; and, as we shall presently see, it is formed in a similar manner. Upon the walls of the cavity, all the tubuli open; and they radiate from this towards the surface of the upper part of the tooth, as shown in Fig. 56. The central cavity is continued as a canal through each fang or root; and the dentinal tubes in like manner radiate from this, towards the surface of the fang.—In the teeth of many of the lower animals, however, we find a network of canals extending through the substance of the tooth, instead of a single cavity; and these canals are frequently continuous with the Haversian canals of the subjacent bone, so that the analogy between the two is complete. From each canal the dentinal tubuli radiate, just in the manner of the canaliculi of bone (§ 295); and thus we may regard a tooth of this kind as repeating, in each of the parts surrounding one of these canals, the structure of the human tooth.

313. The process by which the cellular mass, or *pulp*, of the dental papilla, becomes converted into the dentine of the perfect tooth, has not been so clearly made-out as to be beyond all question. The following, however, is the account given of it by Mr. Tomes,†

* Oblique section of Dentine of human tooth, highly magnified, showing the parallel tubuli.

† Lectures on Dental Physiology and Surgery.

who has very carefully examined it. The dentinal pulp is at first composed of a mass of nucleated cells, held together by a meshwork of delicate fibres and bands, constituting an imperfect form of areolar tissue, the interspaces between them being occupied by a homogeneous plasma. In the part which is nearest to the coronal surface of the tooth, when calcification is about to commence, the areolar tissue has usually disappeared, and its place is occupied by a finely-granular gelatinous substance. The cells are at first disposed without any regularity in the midst of this; but immediately preceding the conversion of the pulp into dentine, the cells are seen to enlarge, and to become arranged in lines nearly parallel to each other and perpendicular to the coronal surface of the tooth; they then elongate in such a manner, that their extremities come into apposition; and they finally coalesce, so that each row of cells forms a continuous tube. Whilst this change is in progress, the gelatinous intercellular substance is becoming consolidated by calcareous deposit; which also hardens the thick walls of the tubes, so that only their interior, formed by the coalescence of the original cell-cavities, remains uncondensed, thus constituting the dentinal tubuli. This process takes-place first on the surface of the pulp, and gradually extends inwards. As the more external and larger cells become hardened, the inner ones increase in size, assume the linear arrangement, and in their turn become converted, with the intercellular substance, into tubular dentine; until at last the great bulk of the pulp is thus transformed, leaving only a comparatively small portion, which, with its nerves and blood-vessels, occupies the central cavity of the tooth.—Thus the substance of the outer portion of the pulp is actually *converted* into dentine, and does not form it by a process of *excretion*, as was formerly supposed. Sometimes it happens that the normal changes are interrupted, and that some of the original meshwork remains persistent; and it is probably to this that the appearance of large cells, not unfrequently seen in Human teeth (Fig. 55), is due.

314. Although in the most characteristic form of Dentine, no blood-vessels exist, yet there are certain species, both among Mammals, Reptiles, and Fishes, in which the Dentine is traversed by cylindrical prolongations of the central cavity, conveying blood-vessels into its substance; and the presence of these medullary canals, giving to the Dentine a vascular character, thus increases its resemblance to bone.—The central portion of the pulp is sometimes converted into a substance still more nearly resembling bone, having its stellate lacunæ as well as its vascular canals. This change is normal or regular in certain animals, as in the extinct Iguanodon and Ichthyosaurus, and in the Cachalot or Sperm-whale; and the ossified pulp bears a close resemblance to the bones of the respective animals, although it is not formed in continuity with them. A similar change occurs in the Human tooth;

—sometimes, it would appear, rapidly, as the result of disease; but in general more slowly, increasing gradually with the advance of age.

315. It is not easy to ascertain the amount of nutritive change that takes-place in the substance of Dentine, when it is once fully formed. When young animals are fed with colouring-matter, it is found to tinge their teeth, as well as their bones; and if the tooth be in process of rapid formation at the time of the experiment, the progressive calcification of the pulp, from without inwards, is marked by a series of concentric lines. Even in the adult, some tinge will result from a prolonged use of this substance; and it has been noticed that the teeth of persons who have long suffered from Jaundice, sometimes acquire a tinge of bile. These facts show that, even after the complete consolidation of the Dentine, it is still pervious to fluids: and that in this manner it may draw into itself, from the vascular lining of the pulp-cavity, a substance capable of repairing its structure, is proved by the circumstance, that a new layer of hard matter is occasionally thrown-out upon a surface which has been laid bare by caries.

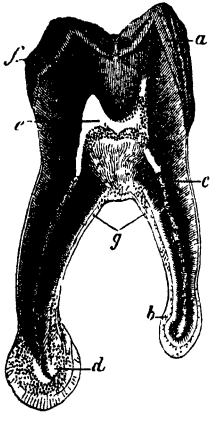
316. In those simple teeth which consist solely of Dentine, the mode of production already described,—that of the consolidation of a papilla upon the mucous membrane of the mouth,—is all which is requisite. When the formation of the tooth itself is complete, it may remain attached only to the mucous membrane, which is the case in the Shark, or it may grow downwards, by the addition of new dental structure at its base, until it comes in contact with the bone of the jaw. Where it is only attached to the mucous membrane, as in the Shark, it is very liable to be torn away; but a new tooth, formed from a distinct papilla, is ready to replace it; and this process is continually repeated, the development of new papillæ being apparently unlimited. On the other hand, where the root of the tooth comes in contact with the jaw, it may completely coalesce with it, which is the case in many Fishes, the Haversian canals of the bone being continued as medullary canals into the dentine; or it may send long spreading roots into the bone, which are united to it at their extremities. In the classes of Fishes and Reptiles (with scarcely any exceptions) the teeth are by no means permanent, as among Mammalia; but new teeth are continually succeeding the old ones. When these teeth do not originate, as in the Shark and most other Fishes, from new and independent papillæ, they originate by a sort of gemmation or budding from the capsules of their predecessors; as will be understood when the *capsular* development of all the higher forms of the dental apparatus has been described.

317. It is obvious that there is no provision, in the simple calcification of the dental papilla, for any variations of density, other than those which may result from the different degrees of hardness

in the substance of the dentine itself. But in the teeth of Man and most other Mammals, and in those of many Reptiles and some Fishes, we find two other substances, one of them harder and the other softer than Dentine; the former is termed *Enamel;* and the latter *Cementum* or *Crusta petrosa.* For the development of these, a peculiar modification of the apparatus is requisite.

318. The *Enamel* is composed of long prismatic cells, exactly resembling those of the prismatic shell-substance formerly described (§ 281), but on a far more minute scale; the diameter of the cells not being more, in Man, than 1-5600th of an inch. The length of the prisms corresponds with the thickness of the layer of enamel; and the two surfaces of this layer present the ends of the prisms, which are usually more or less regularly hexagonal. The quantity of animal matter in the enamel of the adult is extremely minute,—not above 2 parts in 100; and it is only at a very early age, that the true character of the animal structure can be distinctly seen. Of the 98 parts of mineral matter in the enamel, 88½ consist (according to Berzelius) of phosphate of lime, 8 of carbonate of lime, and 1½ of phosphate of magnesia. The course of the prismatic cells is more or less wavy; and they are marked by numerous transverse striæ, resembling those of the prismatic shell-substance, and probably originating in the same cause,—the coalescence of a line of shorter cells, to form the lengthened prism. The Enamel is usually destitute of tubuli; but Mr. Tomes has shown that it is occasionally penetrated by prolongations of the tubuli of the dentine, and that this peculiarity, which is occasional and abnormal in Man, is characteristic of the teeth of many Marsupials. In density and resisting power, the Enamel far surpasses any other organized tissue, and approaches some of the hardest of mineral substances. In Man, and in Carnivorous animals, it covers the crown of the tooth only, with a simple cap or superficial layer of tolerably uniform thickness (Fig. 56, *a*), which follows the surface of the dentine in all its inequalities; and its component prisms are directed at right angles to that

Fig. 56.*



* Vertical section of Human molar Tooth:—*a*, enamel; *b*, cementum or crusta petrosa; *c*, dentine or ivory; *d*, osseous excrescence, arising from hypertrophy of cementum; *e*, cavity; *f*, osseous cells at outer part of dentine.

surface, their inner extremities resting in slight but regular depressions on the exterior of the dentine. In the teeth of many Herbivorous animals, however, the Enamel forms (with the Cementum) a series of vertical plates, which dip-down (as it were) into the substance of the dentine, and present their edges alternately with it, at the grinding surface of the tooth; and there is in such teeth no continuous layer of dentine over the crown. The purpose of this arrangement is evidently to provide, by the unequal *wear* of these three substances,—of which the Enamel is the hardest and the Cementum the softest,—for the constant maintenance of a rough surface, adapted to triturate the tough vegetable substances on which these animals feed.—The Enamel is the least constant of the dental tissues. It is much more frequently absent than present in the teeth of the class of Fishes; it is wanting in the entire order of Ophidia (Serpents) among existing Reptiles; and it forms no part of the teeth of the Edentata (Sloths, &c.) and Cetacea (Whales) amongst Mammals.

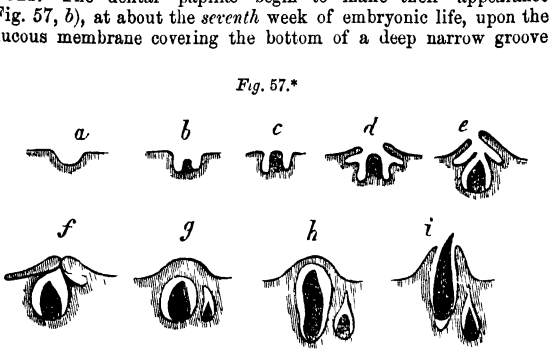
319. The *Cementum*, or *Crusta Petrosa*, has the characters of true Bone; possessing its distinctive stellate lacunæ and radiating canaliculi. Where it exists in small amount, we do not find it traversed by medullary canals; but, like Dentine, it is occasionally furnished with them, and thus resembles Bone in every particular. These medullary canals enter its substance from the exterior of the tooth, and consequently pass towards those which radiate from the central cavity towards the surface of the dentine, where the latter possesses a similar vascularity; as was remarkably the case in the teeth of the extinct Megatherium.—In the Human tooth, however, the Cementum has no such vascularity. It forms a thin layer, which envelopes the root of the tooth, commencing near the termination of the capping of Enamel (Fig. 56, *b*). This layer is very subject to have its thickness increased, especially at the extremity of the fangs, by hypertrophy, resulting from inflammation; and sometimes large exostoses (*d*) are thus formed, which very much increase the difficulty of extracting the tooth. When the tooth is first developed, the Cementum envelopes its crown, as well as its body and root; but the layer is very thin where it covers the Enamel, and being soft, it is soon worn-away by use. In the teeth of many Herbivorous Mammals, it dips-down with the Enamel to form the vertical plates of the interior of the tooth; and in the teeth of the Edentata as well as of many Reptiles and Fishes, it forms a thick continuous envelope over the whole of the surface, until worn-away at the crown.

320. The development of these additional structures is provided-for by the enclosure of the primitive papilla, from which the dentine is formed, within a Capsule, which, at one period, completely covers it in: between the inner surface of the capsule, and the outer surface of the dentinal papilla, a sort of epithelium is developed, by

the calcification of a part of which the Enamel is formed; and the Cementum is generated by the conversion of the capsule itself into a bony substance.—The processes by which this capsular investment is produced, and the tooth completed and evolved, will now be briefly described, as they occur in the Human fœtus.

321. The dental papillæ begin to make their appearance (Fig. 57, *b*), at about the *seventh* week of embryonic life, upon the mucous membrane covering the bottom of a deep narrow groove

Fig. 57.*



(Fig. 57, *a*), that runs along the edge of the jaw; and during the *tenth* week, processes from the sides of this 'primitive dental groove,' particularly the external one, begin to approach one another, so as to divide it by their meeting into a series of open follicles, at the bottom of which the papillæ may still be seen. At the *thirteenth* week, all the follicles being completed, the papillæ, which were at first round blunt masses of cells, begin to assume forms more characteristic of the teeth which are to be developed from them; and by their rapid growth, they protrude from the mouths of the follicles (Fig. 57, *c*). At the same time, the edges of the follicles are lengthened into little valve-like processes, or *opercula*, which are destined to meet and form covers to the follicles (*d*). There are two of these opercula in the Incisive follicles, three for the Canines, and four or five for the Molars. And by the fourteenth week, the two lips of the dental groove meet over the mouths of the follicles, so as completely to enclose each papilla in a distinct capsule (*e*).—At this period, before the calcification of the primitive pulps commences, a provision is made for the production of the second or permanent molars; whose capsules originate in buds or offsets from the upper part of the capsules of the temporary or milk-teeth (*f*). These offsets are in the condition of open fol-

* Successive stages of the development of the Deciduous or Temporary Teeth, and of the origin of the capsules of the Permanent set.

licles, communicating with the cavity of the primitive tooth; but they are gradually closed-in, and detached altogether from the capsules of the milk-teeth (*g*, *h*, *i*).

322. Soon after the closure of the follicles of the Milk-teeth, the conversion of the cells of the original papilla into Dentine commences, according to the method already described (§ 313). Whilst this is going-on, the follicles increase in size, so that a considerable space is left between their inner walls and the surface of the dental papillæ; which space is filled-up with a gelatinous granular matter, the Enamel-pulp. The portion of this which is converted into enamel, however, is very small; being only a thin layer, which is left on the inner surface of the capsule after the remainder has disappeared. The interior of the dental sac, at the time when the conversion-process has reached the base of the dentinal pulp, is in the villous and vascular condition of a Mucous membrane,—which indeed it really is, having been, as we have seen, once continuous with the lining of the mouth; whilst the layer of prismatic cells which covers its free surface, and by the calcification of which the enamel is produced, may be regarded as an epithelium.—The completion of the Enamel, and the ossification of the capsule so as to form the Cementum, take place at a subsequent period.

323. We have thus seen that the history of the first development of the Human teeth may be divided into three stages, the *papillary*, the *follicular*, and the *saccular*. The papillary corresponds precisely with the complete mode of dental development in the Shark and other Fish,—as already mentioned. The follicular, which commences with the enclosure of the papillæ in open follicles, and terminates when the papillæ are completely hidden by the closure of the mouths of those follicles, has also its permanent representation in the development of the teeth of many Reptiles and Fishes; the primitive papillæ of which, though enclosed in follicles, are never covered-in at the summit, and thus free themselves from their envelopes by simply growing upwards through their open mouths. But in Man, and in all other animals which agree with him in going-on to the saccular stage, there must also be an *eruptive* stage, which consists in the bursting-forth of the tooth from the enclosing capsule; the summit of the tooth being carried against the lid of the sac, by the growth of its root (Fig. 57, *h*). By the continuance of the same growth, the teeth are caused to penetrate the gum, and are gradually raised above its surface (Fig. 57, *i*).

324. All the permanent teeth, which are destined to replace the temporary set, originate, as already stated, in buds or offsets from the capsules of the latter. But behind the last temporary molars, which are replaced by the permanent bicuspids, three permanent molars are to be developed on each side of either jaw. The *first* of these is formed on precisely the same plan with the milk-teeth; but is not completed until a later period. The capsule of the *second*

is formed at a later period from that of the first, by a process of budding exactly analogous to that by which the other permanent capsules are formed from the corresponding temporary; and at a still later period, the capsule of the *third* permanent molar is formed as a bud from that of the second. The evolution of this molar does not usually take-place, until the system has acquired its full development; and the process of budding then ceases in Man,—being limited to a single act of reproduction in the case of the ordinary Milk-teeth, and to a double one in that of the first permanent Molar. In many animals of the lower classes, however, the process goes-on through the whole of life without any limit; the newly-formed teeth, however, usually taking the places of those of the previous set, and not being developed at their sides like the second and third permanent molars of Man. By a process of this kind, the continual renewal of the teeth is effected in those Reptiles and Fishes, whose dentition goes-on to the saccular stage; in those at which it stops at the papillary, the successive teeth are formed from new and independent papillæ. The analogy between the continued succession of teeth in the lower Vertebrata, by the gemmiparous reproduction of their capsules, and the development of the capsules of the permanent teeth of Man from those of the temporary set, is made further evident by the fact, that a *third* set occasionally makes its appearance in persons advanced in life; the development of which would not be intelligible, if we could not refer it to the continuance of the same process in the other capsules, as that which regularly takes-place to a limited extent in the permanent molars of Man, and which goes-on without limit through the whole lives of the lower Vertebrata.

325. We occasionally meet with teeth in certain Mammalia,—such as the tusks of the Elephant, the two large front teeth of the Rodents, and the grinders of the Sloths,—which are constantly in a state of growth, their pulps being *persistent*, and not being closed-in by the growth of fangs. In such teeth, the base of the pulp remains unconverted, and a new development of cells is continually taking place in that situation; these new cells are in their turn converted into dentine, in continuity with that previously formed; and thus the tooth or tusk is continually lengthening at its base, in a degree which compensates for its usual wear at its summit. If anything should prevent that wear,—as when the opposite tooth has been broken-off,—there is an absolute increase in the length of the tooth, from the continued growth at its base; which may become a source of great inconvenience to the animal. There is nothing in the Human subject at all analogous to this mode of development from persistent pulps; the process being checked by the closure of the root around the base of the pulp, which obstructs the supply of blood it receives. The chief exception to the rule that no Reptiles or Fishes have permanent teeth, is found in the curious *Dicynodon*,

an extinct Reptile which had two large tusks growing from persistent pulps.

326. The following table shows the usual periods at which the different teeth of the two sets first show themselves above the gum. It must be borne in mind, however, that these periods are subject to very great variation; and that the average alone can therefore be expressed.

Temporary or Deciduous Teeth.	Months.	*Permanent Teeth.*	Years.
Central Incisors	7	First Molars	6½ to 7
Lateral Incisors	8—10	Central Incisors	7 — 8
Anterior Molars	12—13	Lateral Incisors	8 — 9
Canines	14—20	First Bicuspids	9 —10
Posterior Molars	18—36	Second Bicuspids	10 —11
		Canines	12 —12½
		Second Molars	12½—14
		Third Molars	16 —30

327. We have seen that the Teeth are formed, in the first instance, upon the *surface* of the Mucous membrane of the mouth; and consequently they really form a part of the *external* or dermo-skeleton, and not of the *internal* or osseous skeleton. They correspond, therefore, with the external skeletons of the Invertebrata; and thus the analogy which has been pointed-out, between the enamel of teeth and the prismatic cellular substance of the shells of Mollusca, and between the dentine and the shells of the higher Crustacea, holds good also in regard to the situation of these structures. Although the teeth are the only ossified portions of the dermo-skeleton in Man, we find the bodies of certain Mammalia, Reptiles, and Fishes, to be partially or completely enclosed in an armour of bony scales or plates; and in some species of the last-named class, which have now ceased to exist, the scales seem to have had a texture very like that of Enamel.

328. In connection with the Teeth, the structure and development of the *Hair* may be described; this substance being generated very much in the same manner as dentine,—by the conversion of a pulp enclosed in a follicle; though the product of the transformation is very different. The Hair-follicle is formed by the inversion of the Skin, as the Tooth-follicle is by an inversion of the Mucous membrane; and it is lined by a continuation of the epidermis. From the bottom of the follicle, a sort of papilla rises-up, formed of cells; the exterior of this, which is the densest part, is known as the *bulb;* whilst the softer interior is termed the *pulp.* The follicle itself is extremely vascular; and even the bulb is reddened by a minute injection; though no distinct vessels can be traced into it.—It was formerly imagined that the Hair, like the other extra-vascular tissues, is a mere product of secretion; its mate-

rial, which is chiefly horny matter of the same composition with that of the epidermis and its other appendages (§ 227), being elaborated from the surface of the pulp. This, however, proves to be a very erroneous account of it; as is shown by the results of microscopic inquiries into its structure, which is very definitely organized. Although the Hairs of different animals vary considerably in the appearances they present, we may generally distinguish in them two elementary parts; a *cortical* or investing substance, of a fibrous horny texture; and a *medullary* or pith-like substance occupying the interior. The fullest development of both substances is to be found in the spiny hairs of the Hedgehog, and in the quills of the Porcupine, which are but hairs on a magnified scale. The cortical substance forms a dense horny tube, to which the firmness of the structure seems chiefly due; whilst the medullary substance is composed of an aggregation of very large cells, which seem not to possess any fluid contents in the part of the hair that is completely formed. The structure of the feather of Birds is precisely analogous the cortical horny tube existing alone in the quill, but being filled with a cellular medulla in the stem of the feather itself. The smaller hairs of the Sable (Fig. 58) show the cortical and medullary substances in a very characteristic form, the former being here plainly seen to be made up of flattened imbricated cells resembling those of the epidermis; whilst the cells of which the latter is composed are nearly globular. In the hair of the Musk-deer (Fig. 59), we find the medullary

Fig 58.*

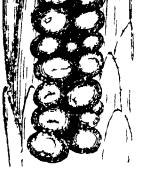
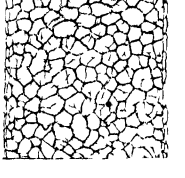


Fig. 59 †



substance to be composed of an assemblage of cells whose walls are flattened against each other, as in a Vegetable pith; whilst the cortical envelope is scarcely distinguishable. In the hair of the

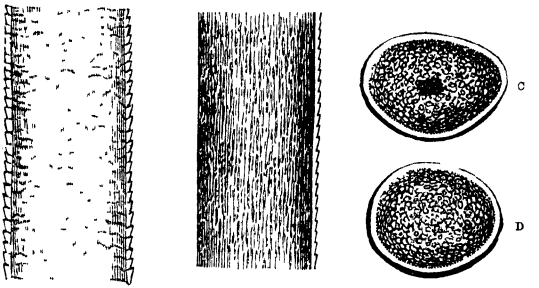
* Hair of *Sable*, showing the large rounded cells in its interior, covered by imbricated scales or flattened cells.

† Hair of *Musk-deer*, consisting almost entirely of polygonal cells.

Mouse and other small Rodents, we see the horny tube crossed at intervals by partitions, which are sometimes complete, sometimes only partial; these are the walls of the single or double line of cells, of which the medullary substance is made-up.

329. In the Human hair, the representation of the cortical envelope of the hair of other animals is found in a thin transparent horny film, which is composed of flattened cells or scales, arranged in an imbricated manner, their edges forming delicate lines upon the surface of the hair, which are sometimes transverse, sometimes oblique, and sometimes apparently spiral (Fig. 60, A). Within

Fig. 60.*



this, we find a cylinder of fibrous texture, which forms the principal part of the shaft of the hair; and it is in the centre alone, which is frequently more distinctly cellular, that we find any close resemblance to the ordinary condition of the medullary substance. The constituent fibres of the shaft are marked-out by delicate longitudinal striæ, which may be traced in vertical sections of the hair (B); but they may be still more completely demonstrated by crushing the hair, after it has been macerated for some time in dilute acid. In dark hairs, the pigmentary granules are frequently scattered between the fibres; but they are usually found in greater abundance in the central cells, where they form a dark spot in the middle of the transverse section (C). Sometimes, however, no such collection is seen; and whatever pigmentary matter exists in

* Structure of the Human Hair —A, external surface of the shaft, showing the transverse striæ and jagged boundary caused by the imbrications of the scaly cortex, B, longitudinal section of the shaft, showing the fibrous character of the medullary substance, and the arrangement of the pigmentary matter; C, transverse section, showing the distinction between the cortical and medullary substances, and the central collection of pigmentary matter; D, similar transverse section without the dark centre.

the hair is equally diffused through the whole of it, or, is even accumulated rather towards its exterior (D). This colouring-matter seems related to Hæmatine; it is bleached by chlorine; and when it gives a dark hue to the hair, it usually contains a good deal of iron.

330. The fibres of which the chief part of the shaft is made-up, are probably cells, which have become elongated by the process already noticed (§ 193), and which have at the same time secreted horny matter into their interior. This change is continually going on in the *bulb* of the hair, at the base of the part previously completed; and by the progressive formation of new cells in the bulb, a constant growth of the shaft is provided-for, its outer fibrous portion being formed from the outer portion of the bulb, and the cellular medulla from its softer interior. The imbricated layer of cells which forms the true cortical substance, may be said to be a prolongation of the outer layer of epidermis over the surface of the hair, being developed from the external layer of the bulb, where it is continuous with the epidermic lining of the follicle. The history of the first development of the Hair-follicle bears, in fact, a striking resemblance to that of the tooth-follicle (§ 321); the first appearance of the hair-bulbs being as mere thickenings of the deeper layers of the epidermis at particular spots; and these being gradually received into hollows of the true skin, which grows up around them so as to enclose them in follicles. And it is further interesting to remark, that when one hair succeeds another it is developed from a bulb that has been separated by a kind of gemmation from its predecessor, as in the case of the teeth.—The Hair is constantly undergoing elongation by the addition of new substance at its base; precisely in the same manner as the teeth of certain Mammals grow from persistent pulps. The part once formed usually undergoes no subsequent alteration; but there is evidence that it *may* be affected by changes at its base, the effect of which is propagated along its whole extent. Thus it is well known that cases are not unfrequent, in which, under the influence of strong mental emotion, the whole of the hair has been turned to grey, or even to a silvery white, in the course of a single night; a change which can scarcely be accounted-for in any other way, than by supposing that a fluid, capable of chemically affecting the colour, is secreted at the base of the hair, and transmitted by imbibition through the medullary substance to the opposite extremity.—The knowledge of the organized structure of hair, enables us better to understand some of the effects of disease; and especially of that peculiar affection termed Plica Polonica. The hair of individuals suffering from it is disposed to split into fibres, often at a considerable distance from the roots, and to exude a glutinous substance; and these two causes unite in occasioning that peculiar *matting* of the hair, which has given origin to the name of the

disease. In the hair thus affected, there is evidently a power of transmitting fluid absorbed at the roots; and as it is said that even blood exudes from the stumps, when the hairs are cut-off close to the skin, it is probable that the vascular bulb is prolonged into the hairs by hypertrophy much further than usual.

6. *Of the Muscular and Nervous Tissues.*

331. Most of the tissues which have been hitherto described, differ in no essential particulars from those of Plants; the chief departure from the forms presented by the latter, being in the Fibrous tissues, which, as already observed, are introduced for the sake of facilitating the movements of the several parts of the structure, one upon another. The various *cellular* tissues find their exact representatives in those of the Vegetable fabric; and the denser parts of the Animal, such as Bone, Cartilage, &c., are represented by the solid substances formed by the Plant in the heart-wood of the stem, the stone of fruits, &c.—these substances acquiring their density in precisely the same manner with the Osseous tissues, by the secreting action of their own cells, which draw a solidifying material from the general circulating fluid. But we now come to two tissues of the highest importance in the Animal fabric; the presence of which is, indeed, its distinguishing characteristic. These are the *Muscular* and the *Nervous* tissues. The former is the one by which all the sensible *movements* of the body are effected; whilst the latter furnishes the instrument by which *sensations* are received, and by which the *will* excites the muscles to action, besides serving as the medium for other operations, in which motion is produced without the intervention of either sensation or will. These tissues, with the apparatus of bones and joints on which the muscles act, constitute the purely *animal* portion of the fabric; and if a being could be constructed in which they should be capable of continued activity without any other assistance, it would be in all essential particulars an Animal. But, as we shall presently see, the plans on which these tissues are formed, in fact the very conditions of their existence and activity, are such, that they require constant *nutrition* and *re-formation;* so that the Animal cannot exist, without an apparatus for preparing, circulating, and maintaining in constant purity, a fluid, which shall afford a supply of nutrient materials, and which shall also afford the means of carrying-off the products of the *waste* consequent upon the action of those tissues. This apparatus constitutes the Vegetative portion of the frame, the elementary parts concerned in which have been already noticed.

332. When we examine an ordinary Muscle with the naked eye, we observe that it is made-up of a number of *fasciculi* or bundles of fibres; which are arranged side-by-side with great regularity,

in the direction in which the muscle is to act; and which are united by areolar tissue. These fasciculi may be separated into smaller parts, which appear like simple fibres; but when these are examined by the microscope, they are found to be themselves fasciculi, composed of minuter fibres bound-together by delicate filaments of areolar tissue. By carefully separating these, we may obtain the ultimate *Muscular Fibre*. This fibre exists under two forms, the *striated* and the *non-striated*: the former makes-up the whole substance of those muscles, over which the will has control, or which are usually called into operation through the nerves; whilst the latter exists in the muscles which the will cannot influence, and which are excited to contraction by stimuli that act *directly* upon them. The muscles of the former class minister especially to the *animal* functions; those of the latter to the functions of *organic* or *vegetative* life. The appearance presented by the striated fibres of ordinary muscles, is shown in Fig. 61; that of the non-striated fibres of the muscles of organic life, in Fig 62.

Fig. 61.*

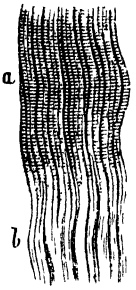
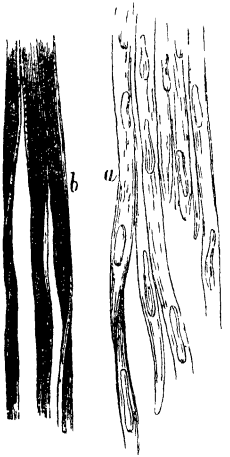


Fig. 62.†



333. When the striated fibre, which must be considered as the highest form of Muscular tissue, is more closely examined, it is seen to consist of a delicate tubular sheath, quite distinct on the one hand from the areolar texture which binds the fibres into fasciculi, and equally distinct from the internal substance of the fibre. This cannot always be brought into view, on account of its transparency; it becomes most evident, when (as occasionally happens) the contents of the fibre are separated transversely by the drawing-apart

* Fasciculus of striated Muscular Fibre, showing at *a* the transverse striæ, and at *b*, the longitudinal striæ.

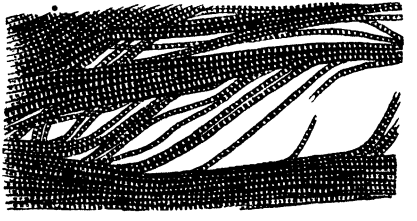
† Non-striated Muscular Fibre; at *b*, in its natural state; at *a*, showing the nuclei after the action of acetic acid.

of its extremities, without the rupture of the sheath; but it may also be sometimes seen rising-up in wrinkles upon the surface of the fibre, when the latter is in a state of contraction. This membranous tube, which has been termed the *Myolemma*, has nothing to do with the production of the striæ; these being due, as will be presently shown, to the peculiar arrangement of its contents. It is not perforated either by nerves or capillary vessels; and forms, in fact, a complete barrier between the real elements of Muscular structure, and the surrounding parts. That it has no share in the contraction of the fibre, is evident from the fact just mentioned, in regard to its wrinkled aspect when the fibre is shortened.

334. Although Muscular Fibres are commonly described as cylindrical in form, yet they are in reality rather polygonal, their sides being flattened against those of the adjoining fibres (Fig. 64). In some instances, the angles are sharp and decided; in others they are rounded-off, so as to leave spaces between the contiguous fibres, for the passage of vessels. In Insects, the fibres often present the form of flattened bands, on which the transverse striæ are very beautifully marked. The size of the fibres is subject to great variation, not merely in different classes of animals, but in different species, in different sexes of the same species, and even in different parts of the same muscle. Thus Mr. Bowman estimates the *average* diameter of the fibres in the Human *male* at 1-352nd of an inch; the *largest* being 1-192nd, and the *smallest* 1-507th. In the *female*, he found the *average* to be 1-454th of an inch; whilst the largest was 1-384th, and the smallest 1-615th. The average size of the Muscular fibre is greater among Reptiles and Fishes, than in other Vertebrata; and the extremes are also much wider. Thus its dimensions vary in the Frog from 1-100th to 1-1000th of an inch; and in the Skate from 1-65th to 1-300th.

335. When the striated Muscular Fibre is examined still more closely, it is found to contain an assemblage of very minute elements, which appear to be cylindrical cells with flattened ends,

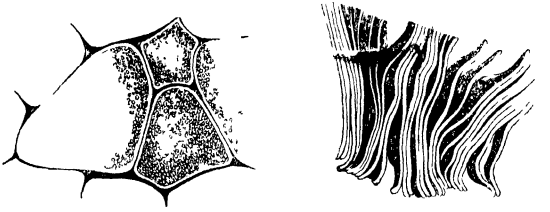
Fig. 63.*



* Striated Muscular Fibre separating into fibrillæ (from a Terebratula).

of very uniform size. These primitive particles are adherent to each other, both by their flat surfaces and by their cylindrical walls. The former adhesion is usually the most powerful; and causes the substance of the fibre, when it is broken-up, to present itself in the form of delicate *fibrillæ*, each of which is composed of a single *row* of the primitive particles (Fig. 65). On the other hand, the lateral adhesion is sometimes the stronger; and causes the fibre to break across into *disks*, each of which is composed of a *layer* of the primitive particles (Fig. 65). Thus the fibre is a solid collection of

Fig. 65.†



these elementary parts, and not hollow in the centre, as some have supposed, is shown by making a thin transverse section of a fasciculus (Fig. 64); by which also the polygonal form of the fibre is made apparent.

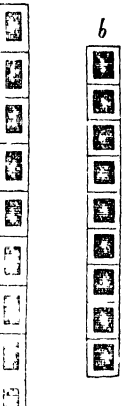
336. When the fibrillæ are separately examined under a high magnifying power, they are seen to present a cylindrical or slightly-beaded-form, and to be made-up of a linear aggregation of distinct cells. We observe the same alternation of light and dark spaces, as when the fibrillæ are united into fibres or into small bundles; but it may be distinctly seen that each light space is divided by a transverse line, and that there is a pellucid border at the *sides* of the dark spaces, as well as between their contiguous extremities (Fig. 66). This pellucid border seems to be the cell-wall; the dark space enclosed by it (which is usually bright in the centre) being the cavity of the cell, which is filled with a highly-refracting substance. When the fibril is in a state of relaxation, as seen at *a*, the diameter of the cells is greatest in the longitudinal direction: but when it is contracted, the fibril increases in diameter as it diminishes in length; so that the transverse diameter of each cell becomes equal to the longitudinal diameter, as seen at *b*; or even exceeds it. Thus the act of Muscular contraction seems to consist in a change

* Transverse section of Striated Muscular fibre, showing the polygonal form of the fibres, and their composition of ultimate fibrils.

† An ultimate Fibre, in which the transverse splitting into disks, in the direction of the striation of the ultimate fibrils, is seen.

of form in the cells of the ultimate fibrillæ, consequent upon an attraction between the walls of their two extremities; and it is interesting to observe, how very closely it thus corresponds with the contraction of certain Vegetable tissues, of which the component cells (§ 345) appear to produce a movement, when they are irritated, by means of a similar change of form. The essential difference, therefore, between the muscular tissue of Animals, and the contractile tissues of Plants, consists in the subjection of the former to nervous influence (§ 353). The diameter of the ultimate fibrillæ will of course be subject to variations, in accordance with their contracted or relaxed condition; but it seems to be otherwise tolerably uniform in different animals, being for the most part about 1-10,000th of an inch. It has been observed, however, as high as 1-5000th of an inch, and as low as 1-20,000th, even when not put upon the stretch. The average distance of the striæ, too, is nearly uniform in different animals; though considerable variations present themselves in every individual, and in different parts of the same muscle. Thus the maximum distance varies in different animals from 1-15,000th to 1-20,000th of an inch; the minimum from 1-7500th to 1-4500th of an inch; while the mean does not depart widely in any instance from 1-10,000th.

Fig. 66.*

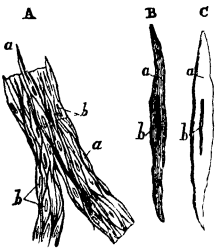


337. The Muscular tissue of Organic Life is very different from that which has been now described. Its fibres are distinguished from the preceding by the absence of transverse markings, and appear to be solid and nearly homogeneous. Their size is usually much less than that of the striated muscular fibre; but owing to the extreme variation in the degree of flattening which they undergo, it is difficult to make even an average estimate of their dimensions; those of the alimentary canal of Man are stated by Dr. Baly to measure from about the 1-2500th to the 1-5600th part of an inch in diameter. These fibres, like those of the other muscles, are arranged in a parallel manner into bands or fasciculi; but these fasciculi are generally interwoven into a network, without having any fixed points of attachment. It is of this kind of structure, that the proper muscular coat of the œsophagus, of the stomach and

* Structure of the ultimate Fibrillæ of Striated Muscular fibre:—*a*, a fibril in a state of ordinary relaxation; *b*, a fibril in a state of partial contraction.

intestinal canal, and of the bladder, is chiefly composed.—Non-striated muscular fibre, however, is capable of being separated, after maceration in dilute nitric acid, into fasciculi of cells, which are usually more or less elongated. These are composed of a soft, light yellow substance, which swells in water and acetic acid, becoming pale in the latter, and which is nearly homogeneous, so that it is difficult to distinguish the cell-wall clearly from the cell-contents; but they are especially characterized by the possession of long staff-like nuclei (Fig. 67, *b*, *b*), which are sometimes only rendered perceptible by acetic acid.

Fig. 67.*



These cells are sometimes so little elongated, especially in the walls of the blood-vessels, that they might be taken for epithelium cells if it were not for their peculiar nuclei; but they are commonly more or less fusiform (Fig. 67, B), and are then arranged in the manner shown in Fig. 67, A, several of such cells being closely united by lateral adhesion in what seems to be a single fibre. This form of muscular structure is often found without any admixture of other tissue, as in the smaller arteries, veins, and lymphatics. But it is most commonly intermingled with the various forms of the simple fibrous tissues; and in this state it is found in the circular coat of the larger arteries and veins, in the erectile tissues generally, in the skin, and especially the dartos, to which it gives a contractility that is manifested under the influence of cold or of mental emotions, and thus produces that general roughness and rigidity of the surface which is known as *cutis anserina*, whilst it throws the scrotum into wrinkles.

338. It has been generally supposed that each Muscular fibre of the striated kind takes its origin, like the straight ducts of Plants, in cells laid end-to-end, forming a tube by their coalescence; within which tube—the Myolemma—the rows of fibrillæ are subsequently developed. The recent researches of Dr. Savory, however, lead to a different idea of the history of the process. According to him, the first stage of it consists in the aggregation and adhesion of the nuclear corpuscles which are scattered through the structureless blastema, and the investment of these corpuscles by distinct portions of condensed blastema. The nuclei, thus aggregated and invested, fall into a single row with remarkable uniformity; and

* Component fusiform cells of Non-striated Muscular fibre:—A, trabecula of spleen, with the cells *in situ*; B, a single cell isolated; C, a similar cell treated with acetic acid;—*a*, *a*, cells; *b*, *b*, nuclei.

this row is bordered on either side with a pellucid band of apparently-homogeneous substance. The fibre next increases in length, and the nuclei become detached from each other, so that at last they are separated by very considerable intervals; and between these intervals, the lateral bands fall-together and coalesce, so that the diameter of the fibre is diminished, except at the points at which the nuclei are imbedded, these presenting varicosities or bulgings. Soon after this separation of the nuclei, some of them begin to undergo disintegration; their substance becomes granular, and their outline broken and interrupted; and presently an irregular cluster of granules is all that remains, which finally disappears. Whilst this is going-on, the striæ begin to show themselves in the previously-pellucid blastema, apparently by the direct conversion of its substance into the component particles (cells?) of the fibrillæ. Fresh nuclei continue, however, to be incorporated into the substance of the fibres from the surrounding blastema; and although these also for the most part undergo disintegration, yet the presence of some may generally be traced even in the muscular fibre of the adult, by treating it with some weak acid; the effect of which is to render the nuclei more opaque, whilst the surrounding structure becomes more transparent (Fig. 68). They are usually numerous in proportion to the size of the fibre. The diameter of the Muscular Fibre of the fœtus is not above one-third of that which it possesses in the adult; and as the *size* of the ultimate particles is the same in both cases, their *number* must be greatly multiplied during the growth of the structure.

Fig. 68.*

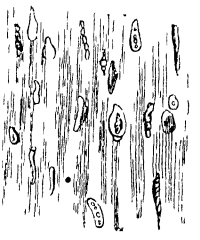


Fig. 69.†



* Mass of Muscular fibres from the pectoralis major of the human fœtus at nine months. These fibres have been immersed in a solution of tartaric acid; and their numerous corpuscles, turned in various directions, some presenting nucleoli, are shown.

† A. Non-striated Muscular fibre from the urinary bladder, showing two of the nuclei.

B. A Muscular fibre of Organic life, from the stomach: the diameter of this and of the preceding fibre, midway between the nuclei, was 1-4750th of an inch.

339. There appears to be no difference, at an early stage of development, between the striated and the non-striated forms of muscular fibre; but whilst the striated fibre goes-on in its development, until the fibrillæ, with their alternation of light and dark spaces, are fully produced, the non-striated fibre retains throughout life an aspect more like that which is characteristic of the embryo; its nuclei being generally very apparent (Fig. 62), and 'nodosities' frequently presenting themselves upon it (Fig. 69).

340. We have seen that the Muscular tissue properly so called, is as extra-vascular as cartilage or dentine; for since its fibres are not penetrated by vessels, the nutriment required for the growth of its contained matter must be drawn by absorption through the myolemma. But the substance of Muscle is extremely vascular; the capillary vessels being distributed in nearly parallel lines, in the minute interspaces between the fibres (Fig. 70); so that there is probably no fibre which is not in close relation with a capillary. Hence there is every provision for the active nutrition of this tissue; the arterial circulation bringing the materials for its growth and renovation; whilst the venous conveys away the products of that waste or disintegration which is consequent upon its active exercise. —The supply of blood is not merely requisite for the *nutrition* of the muscular tissue; it also affords a condition which is requisite for its *action*. This condition is oxygen. It is not enough that blood should circulate through the muscles; for that blood, to exercise any beneficial influence, must be arterialized. Consequently the muscles of warm-blooded animals soon lose their contractile power, after the supply of arterial blood has been suspended, either by the cessation of the circulation, or by the want of aeration of the blood; but those of cold-blooded animals preserve their properties for a much longer period, in accordance with the general principle formerly stated,—that, the lower the usual amount of vital energy, the longer is its persistence, after the withdrawal of the conditions on which it is dependent.

Fig. 70.*

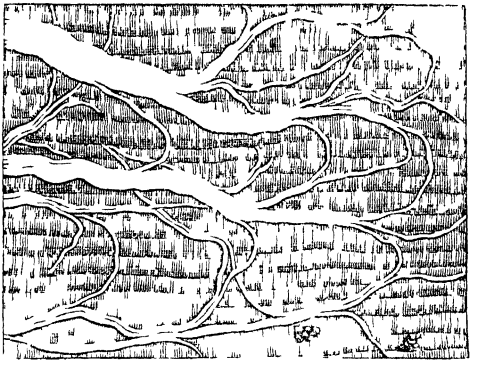


341. The Muscles of Animal Life are, of all the tissues except the Skin, the most copiously supplied with Nerves. These, like the blood-vessels, lie on the *outside* of the Myolemma of each fibre; and their influence must consequently be exerted through it. The

* Capillary net-work of Muscle.

arrangement of these nerves is shown in the succeeding figure Their ultimate fibres or tubes cannot be said to terminate anywhere in the muscular substance, for after issuing from the trunks, they form a series of loops, which either return to the same trunk, or join an adjacent one (Fig 71) The occasional appearance

*Fig 71**



of a termination to a nervous filament is usually caused by its dipping down between the muscular fibres to pass towards another stratum, but it appears from recent inquiries to be sometimes due to a subdivision of the central axis into a brush like group of minute fibrillæ, which form a yet minuter plexus around the muscular fibres —The non striated muscles, however, are very sparingly supplied with nerves and these are derived (for the most part, if not entirely) from the Sympathetic system, rather than from the Cerebro spinal

342 Every Muscular Fibre of the striated kind at least, is attached at its extremities to fibrous tissue, through the medium of which it exerts its contractile power on the bone or other substance which it is destined to move The muscular fibre usually ends abruptly by a perfect disk and the myolemma seems to terminate there The tendinous fibres are attached to the whole surface of the disk, and seem to spread themselves from it over the whole myolemma Thus the whole muscle is penetrated by minute fasciculi of tendinous fibres, and these collect at its extremities into a tendon Sometimes the muscular fibres are attached

* Portion of Muscle, showing the arrangement of the motor Nerves supplying it

obliquely to the tendon, which forms a broad band that does not subdivide; this is seen in the legs of Insects and Crustacea, in which the muscular fibres have what is called a *penniform* arrangement, being inserted into the tendon, on either side, like the laminæ of a feather into its stem.—The *forms* which different muscles present, have reference purely to the mechanical purposes which they have respectively to accomplish. The elements are the same in all, both as regards structure and properties.

343. Notwithstanding the energy of growth in Muscular tissue, it is doubtful if it is ever regenerated, when there has been actual loss of substance. Wounds of Muscles are united by Areolar Tissue, which gradually becomes condensed; but its fibres never acquire any degree of contractility.

344. Muscular fibre has usually been regarded as identical in ultimate composition with the Fibrin of the blood. But, as already stated (§ 173), the two substances, Syntonin and Fibrin, differ in several of their properties; the difference being most strongly-marked in the relative action of dilute muriatic acid upon the two substances. The muscle-substance of veal bears a closer resemblance to the fibrin of blood, than to that of adult muscle.—In ordinary muscle, the solid matter forms about 23 parts in 100; the remainder consisting of water. The solid matter contains about 7½ per cent. of fixed salts.

345. We now come to investigate the remarkable property which is the distinguishing characteristic of Muscular tissue;—that of contracting on the application of a stimulus. Some approaches to this property are manifested by certain Vegetable structures. Thus, if the small enlargement at the base of the footstalk of the leaf of the Sensitive Plant be touched ever so slightly, the leaf will be immediately drawn-down by the contraction of the tissue of the part irritated. If the leaf itself be touched, the same effect results, but apparently through a different channel; the tissue of the leaf contracts where it is touched, and forces some of its fluid along the vessels of the footstalk into the upper side of the little excrescence at its base, by the distension of which the leaf is forced down. In the *Dionœa muscipula*, or Venus's Fly-trap, there is a similar transmission of the effect of the stimulus from one part to another; for the two lobes of the leaf which form the trap, are made to close together, when an insect settles upon either one of three spines which project from the surface of each lobe, or when the points of these spines are touched with any hard body.—Many other instances of Vegetable movement might be brought together. Some of them are obviously produced by an enlargement or contraction of the cells, occasioned by variations in the amount of fluid they contain; and these variations depend upon the hygrometric state of the atmosphere. With these we have nothing to do. But there are many in which (as in the case of the Sensitive-plant first

mentioned) a stimulus applied to a part occasions the immediate contraction of its cells, and a consequent motion in the *same* part. And there are also several in which the contraction produces motion in a *distant* part, as in the Dionæa; but this propagation appears to be of a simply-mechanical character; being accomplished through the medium of fluid, which is forced from one part by its own contraction, and caused to distend another.

346. From these examples, however, it is evident that the property of contractility is not entirely restricted to the Animal kingdom; and we shall find that the simplest form under which it manifests itself in the Animal body, bears a close relationship with that which is displayed in Plants. The non-striated fibre of the alimentary canal, which is subservient to the functions of Vegetative life alone. is called into action much more readily by a stimulus directly applied to itself, than it is in any other mode. Such is not the case, however, with the striated fibre, of which the muscles of Animal life are composed; this being much more readily called into action by a peculiar stimulus conveyed through the nerves supplying those muscles, than by any other that may be more directly applied to them.

347. The Contractility of Muscular Fibre shows itself under two forms. Its most obvious and striking manifestations are those that occur in the voluntary muscles and in the heart; which, when in action, exhibit powerful contractions alternating with relaxations. The property which is concerned in these, is distinguished as *Irritability*. On the other hand, we find that these same muscles exhibit a tendency to a moderate and permanent contraction, which is not shown by them when they are dead, and which cannot therefore be the result of elasticity or of any simple physical property; this endowment, which seems to exist in the greatest amount in certain forms of the non-striated fibre, is called *Tonicity*.

348. That the Irritability of Muscles is a property inherent in them, and is in this respect analogous to the peculiar vital endowments of any other form of tissue, cannot be any longer a matter of doubt; though many Physiologists have sought to show, that it is in some way derived from the nerves. Not only may an entire Muscle be made to contract, by the application of a proper stimulus, long after the division of the nervous trunks supplying it; but even a single fibre, completely isolated from all its nervous connections, may be seen to contract under the Microscope. Moreover in the non-striated muscular fibre, it is often difficult to excite contractions through the nerves at all, when a stimulus directly applied to itself will immediately produce sensible and vigorous movements. The energy of the contractile power depends in great part upon the state of nutrition of the muscle; and this again is influenced by the degree in which it is exercised. Now as the Muscles of Animal Life are all excited to action, in the usual state

of things, through the medium of their nerves, it follows that if the nerves be paralysed, the muscles will be seldom or never called into use. When disused they will receive very little nourishment; the disintegrating changes will not be counterbalanced by reparative processes; and in consequence, the muscular structure will be gradually so far impaired as to lose its peculiar properties, and will even, in time, almost totally disappear. Yet even after the almost complete departure of muscular contractility, through the metamorphosis of the structure consequent upon disuse, it may be again recovered if the muscles be called into exercise; but the recovery of the power is very slow, and proceeds *pari passu* with the improvement in the nutrition of the part, being more tedious in proportion to the length of the previous disuse.

349. That the Irritability of Muscular fibre belongs to itself, and is not derived in any way from the nerves, is further shown in the following manner. If a set of muscles (as those of the leg of a Rabbit or Frog) be repeatedly thrown into action by galvanism, until the stimulus no longer occasions their contraction, their irritability is then said to be exhausted; by rest, however, it is recovered,—the nutritive processes making-good the loss previously suffered. Now it has been shown by Dr. J. Reid, that this recovery may take place, even after the division of all the nerves supplying the limb; provided that the nutrition of the part be not interfered with. It has been further shown by the same excellent Physiologist, that, if the nerves of a limb be divided, the loss or retention of the contractility of the muscles entirely depends upon the degree of exercise to which they are subjected, and consequently upon the nutrition they receive. The muscles of the hind-leg of a Rabbit, whose sciatic nerve had been divided, were found to lose their contractility almost completely in the course of seven weeks. They were much smaller, paler, and softer, than the corresponding muscles of the opposite leg; and they scarcely weighed more than half as much as the latter. Now when the nerves of *both* hind-legs of a Frog were cut, and the muscles of *one* of the limbs thus paralysed were daily exercised by a weak galvanic battery, while those of the other were allowed to remain at rest, it was found after the lapse of two months, that the muscles of the exercised limb retained their original size and firmness, and contracted vigorously, whilst those of the other had shrunk to one-half their former size. Though the latter still retained their contractility, there could be no doubt that they would soon lose it, by the progress of the change already far advanced in their physical structure; this change not being as rapid in cold-blooded animals, as in Birds and Mammals.

350. By these and other facts, then, it may be regarded as completely proved, that the Irritability of Muscles is a vital endowment, belonging to them in virtue of their peculiar structure;—that, so long as this structure is maintained in its normal condition by the

nutritive processes, so long is the property capable of being manifested;—but that any cause which interferes with the nutrition of a muscle, impairs or destroys its irritability. No cause is so effectual in doing this, as complete *disuse;* and no means is so sure to produce complete disuse of a muscle, as the division of its nerve, since its being called into exercise in any other way is very improbable; hence the section of the nerve is almost certain to produce, in time, the loss of the contractility of the muscle. But if a means be devised, by which the muscle may still be called into action in any other way,—as in Dr. Reid's experiment just quoted,—its irritability is retained, because its regular nutrition is kept-up.

351. We have now to inquire, then, into the circumstances under which this peculiar endowment acts; or the means by which it may be called into operation, the mode in which the contraction takes-place, and the conditions which are necessary for its performance.—All Muscular Fibre, which has not lost its contractility, may be made to contract by a stimulus applied *directly* to itself; and this stimulus may be of different kinds. The simplest is the contact of a solid substance; thus we may excite muscular contraction by simply touching the fibre, just as we cause contraction in the tissue of the Dionæa or Sensitive Plant. Most substances of strong chemical action, such as acids and alkalies, will call-forth the contractility of muscular fibre, when applied to it; and the same result is produced by heat, cold, and electricity,—the last-named agent being the most powerful of all. The effect of the application of any of these stimuli varies considerably, according to the kind of Muscle on which it is exerted. If we irritate a portion of a muscle composed of striated fibre (any one of the voluntary muscles for example), the fasciculus of fibres which is touched will immediately contract, and that one only; and the contracted fasciculus will soon relax, without communicating its movement to any other.

352. If we irritate a portion of non-striated fibre, however, as that of the Alimentary canal, the fasciculus which is stimulated will contract less suddenly, but ultimately to a greater amount; its relaxation will be less speedy; and before it takes place, other fasciculi in the neighbourhood begin to contract; their contraction propagates itself to others; and so on. In this manner, successive contractions and relaxations may be produced through a considerable part of the canal, by a single prick with a scalpel; a sort of wave of contraction being transmitted in the direction of its length, and being followed by relaxation. Again, in the Muscular structure of the Bladder and Uterus, powerful contractions are excited by irritation, and these produce a great degree of shortening; but they do not alternate in the healthy state with any rapid and decided elongation; whilst, on the other hand, an irritation applied to one spot causes more extensive contractions than are seen to occur as its

immediate consequence in the preceding cases. In the Heart, the muscular structure of a large part of the organ is thrown into rapid and energetic contraction, by a stimulus applied at any one point; and this contraction is speedily followed by relaxation. And in the fibrous tissue of the middle coat of the Arteries, the contraction takes-place rather after the manner of that of the bladder and uterus, and a prolonged application of the stimulus is often necessary to produce the effect; but when the contraction commences, it produces a considerable degree of shortening, which takes-place in other fasciculi than those directly irritated, and does not speedily give way to relaxation.

353. On the other hand, when the stimuli which excite muscular contraction are applied to the Nerve which supplies a voluntary muscle composed of striated fibre, they produce a simultaneous contraction in the whole muscle; the effect of the stimulus being at once exerted upon every part of it. In the ordinary action of such muscles, the nervous system is always the channel through which they are called into play, whether to carry into effect the determinations of the mind (§ 391), or to perform some office necessary to the continuance of life, such as the movements concerned in Respiration (§ 394). The nerves of the striated fibre are all derived at once from the Cerebro-Spinal system.—The ordinary actions of the non-striated fibre, on the contrary, are executed in respondence to stimuli applied directly to themselves. It is so difficult to excite contractions in it through the medium of its nerves, that many Physiologists have denied the possibility of doing so; and the nerves lose their power of conveying the influence of stimuli very soon after death, although the contractility of the muscles may remain for a considerable time. The nerves of the non-striated fibre are chiefly those belonging to the Sympathetic system; but, as will be shown hereafter (CHAP. XII.), those which excite motion are probably derived in reality from the Cerebro-spinal system, through the communicating branches which unite the two.

354. When a Muscle is thrown into contraction, its bulk does not appear to be at all affected. Its extremities approach, so that it is shortened in the direction of its fibres; but its diameter enlarges in the same proportion. It was formerly supposed that the ultimate fibres, in the act of contraction, threw themselves into zig-zag folds; but this is now well-ascertained not to be the case. The fibre, like the entire muscle, preserves its straight direction in shortening, and increases in diameter. The fibrillæ themselves, as already mentioned (§ 336), exhibit an evident change in regard to the distances of their successive light and dark portions; and the fibre which is made-up of these, exhibits, in its contracted state, a very close approximation of the transverse striæ; to such an extent that they become two, three or even four times as numerous in a given length, as they are in a similar length of a non-contracted fibre. According

to Mr. Bowman's observations, the contraction usually commences at the extremities of a fibre; but it may occur also at one or more intermediate points. The first appearance of contraction is a dark spot, caused by the approximation of the striæ; and this gradually extends itself, so as to involve a greater or less proportion of the length of the fibre. The approximation of the solid portions forces out the fluid which was previously contained amongst the fibrillæ; and this is seen to lie in bullæ or blebs beneath the myolemma, which is drawn-up into wrinkles.

355. The successive stages of the act of contraction can only be thus observed, when it takes place very slowly, as in the *rigor mortis*, or slow contraction after death, the phenomena of which will be presently noticed (§ 367). But the resulting change in muscular fibres which have been made to contract by galvanism or any other stimulus, is essentially the same. This may be best seen in transparent Entozoa, Crustacea, and others among the lower Articulated Animals, whilst alive. Again, in persons who have died from Tetanus, a considerable number of the fibres are found to have been ruptured by violent spasmodic action; the contractile force, called into existence by the powerful stimulation of the nerves, having overcome the tenacity of the fibre: and in such cases, the same approximation of the transverse striæ, and proportional increase in the diameter of the fibre, are to be observed.

356. It appears that, even when considerable force of contraction is being exerted, the *whole* fibre is seldom or never in contraction at once; but that a continual interchange is taking-place amongst its different parts,—some of them passing from the contracted to the relaxed state, as shown by the separation of the transverse striæ,—whilst others are taking up the duty, and passing from the relaxed to the contracted condition, as shown by the approximation of the striæ. But it is not only among the different parts of the individual fibres, that this interchange seems to take-place. There is good reason to believe, that, when a muscle is kept in a contracted state, by an effort of the will, for any length of time, only a part of its fibres are in contraction at any moment; but that a continual interchange of condition takes-place amongst them, some contracting whilst others are relaxing, so that the entire muscle remains contracted, whilst the state of every individual fibre may have undergone a succession of alterations. When the ear is applied to a muscle in vigorous action, an exceedingly rapid faint silvery vibration is heard, which seems to be attributable to this constant movement in its substance.

357. Thus it appears that the prolongation of the contraction of a muscle through any length of time, is not opposed to the fact that, in the individual fibres, relaxation speedily follows contraction; but it is only a peculiar manifestation of it. The ordinary movements of the Heart exhibit a different manifestation; its fibres con-

tracting simultaneously, and relaxing together, instead of alternating amongst themselves like those of a voluntary muscle.—The occasional zig-zag arrangement of the fibres, which has been supposed to be their contracted state, is really dependent upon the approximation of their extremities, in consequence of the contraction of some neighbouring fibres, whilst their own condition is that of relaxation. It may be artificially produced by bringing together the two extremities of a fasciculus, after the irritability of the fibre has ceased; so that the flexure at determinate points must be owing simply to the physical arrangement of the parts,—perhaps to the passage of nerves or vessels in a transverse direction.

358. We have now to consider the conditions which are requisite for the manifestation of Muscular Irritability. It has been already pointed-out, how close is the dependence of the property upon the due *nutrition* of the tissue; but the property cannot be long exercised except under another condition, which is consequently of almost equal importance,—the circulation of *oxygenated blood* through the substance of the muscle. The length of time during which the contractility remains, after the circulation has ceased, has been shown by Dr. M. Hall to vary inversely to the activity of the respiration of the animal. In *cold*-blooded animals, the standard of whose respiration is low, the contractility remains for many hours after death, even in the voluntary muscles; and the muscles of organic life retain it with great tenacity. Thus the heart of a Frog will go-on pulsating for many hours after its removal from the body; and the heart of a Sturgeon, which had been inflated with air and hung-up to dry, has been seen to continue beating, until the auricle had absolutely become so dry as to rustle during its movements. An exceedingly feeble Galvanic current is sufficient to excite the muscles of these animals to contraction; so that Matteucci, in his experiments upon Animal Electricity, has been accustomed to use the prepared hind-leg of a Frog as the best indicator of the passage of an electric current. Among *warm*-blooded animals, whose respiration is vastly more active, the duration of the irritability is proportionally abbreviated; and the muscles of Birds, whose respiration is peculiarly energetic, lose this property at an earlier period after the cessation of the circulation, than do those of Mammals. From experiments on the bodies of executed criminals, who were previously in good health, Nysten ascertained that, in the Human subject, the contractility of the several muscular structures, as tested by Galvanism, departs in the following time and order;—the left ventricle of the heart first; the intestinal canal at the end of 45 or 55 minutes; the urinary bladder nearly at the same time; the right ventricle after the lapse of an hour; the œsophagus at the expiration of an hour and a half; the iris a quarter of an hour later; and lastly, the ventricles of the heart, especially the right, which in one instance contracted 16½ hours after death.

359. That the circulation of arterial or oxygenated blood through the muscles, is the essential condition of the continuance of their irritability, appears from this,—that after the general death of the system, and even after the removal of the brain and spinal cord, the muscles will preserve their irritability, and the action of the heart itself will continue for a long time, provided that the circulation through the lungs be kept-up by artificial respiration, on the principles hereafter to be explained (§ 688). But if, whilst the general circulation continues, the circulation through a particular muscular part be interrupted, that organ will lose its contractility earlier than usual. Thus it has been shown by Mr. Erichsen, that if the coronary arteries (supplying the substance of the heart) be tied in a dog or a rabbit, after the animal has been pithed, and the circulation is being maintained by artificial respiration, the pulsation of the heart will only go-on for about 23 minutes after the ligature has been applied, or about 33 minutes after the death of the animal; instead of continuing for 90 minutes, as it will do under other circumstances. Further, if blood charged with carbonic acid, instead of with oxygen, circulate through the muscles, their irritability is speedily impaired, and is even destroyed. This is best seen, when animals are killed by being caused to breathe an atmosphere highly charged with carbonic acid; the irritability of their muscles departing as soon as they are dead. In fact, the destruction of the irritability of the heart, by the circulation of venous blood through its substance, is one of the immediate causes of death. A similar effect is produced by the respiration of other gases, which are either poisonous in themselves, or which prevent that interchange of carbonic acid and oxygen which ought to take-place in the lungs. On the other hand, when animals have been made to respire oxygen, and their blood has been consequently highly arterialized, the contractility of their muscles is retained for a longer time than usual.

360. Hence we may conclude the presence of oxygen in the blood to be one of the conditions of muscular contraction; although it is much less essential in the case of cold-blooded, than in that of warm-blooded animals. It is interesting to remark, that the muscles of *hybernating* warm-blooded Mammals are reduced for a time to the level of those of cold-blooded animals, their contractility being retained almost as long as that of the latter;—thus confirming the general principle already stated, as to the relation between the amount of respiration, and the duration of the irritability.

361. The Muscles, as we have seen, are largely supplied with blood; and the flow of blood into them increases with the use that is made of them. The demand for nutrition is obviously augmented, in proportion to the activity of the exercise of the Muscular system; for the slightest observation suffices to show, that a much smaller amount of nourishment is sufficient to sustain the body in its normal

condition, when the Muscular system is not actively exercised, than when it is in energetic operation. The quantity which is ample for an individual leading an inactive life, is far too little for the same person in the full exercise of his muscular powers.—Again, there is evidence derived from observation of the relative amount of the solid matters excreted from the body under different circumstances (§ 731), that a *waste* or *disintegration* of the muscular tissue takes place whenever it is actively employed; and this in a degree strictly proportional to the amount of force which it is called-upon to exercise. In fact, it would appear that this waste is a necessary consequence of the exercise of the muscle; every act of contraction involving the death and decomposition of a certain amount of tissue. And as the presence of oxygen is always necessary for the decomposition of organic substances, so do we find that the penetration of the muscular tissue by oxygenated blood is essential to the manifestation of its contractile power.—Every act of contraction, then, may be said to involve the death of a certain amount of muscular tissue; and, on the principles formerly laid down (CHAP. I., Sect. 3), we may look upon the development of contractile power as an expenditure of the vital force which that tissue previously possessed, and which ceases to exist as such, when the elements of the tissue enter into new combinations.

362. On the other hand, the muscular substance is repaired by an act of nutrition, at the expense of the material supplied to it by the circulating fluid. There are certain muscles, as the heart and the muscles of respiration, whose action is necessarily constant; and their reparation must take-place as unceasingly as their waste. In these muscles, no sense of fatigue is ever experienced. But in the muscles which are usually put in action by the will, this is not the case. Any prolonged exertion of them induces fatigue; and this fatigue is an evidence of their impaired condition, and of the necessity of rest to impart to them a renewal of vigour. The *rest* of muscles is essential to the recovery of their powers; and this recovery is due to the nutritive operations, which then take-place unchecked, and which repair the losses previously sustained. The permanently-increased flow of blood to a muscle, which takes-place when it is continually being called into vigorous action, is thus on the one hand occasioned by the demand for oxygenated blood created by its use, whilst on the other hand it tends to increase the power of the muscle, by an augmentation of its nutrition. Hence it is, that the more a muscle is exercised, the more vigorous and more bulky does it become. This is equally the case, whether the exercise of the muscle be voluntary or not. We see examples of it in the arms of the smith and in the legs of the opera-dancer; and we have a still more striking manifestation of it in those cases, in which an obstruction to the exit of urine through the urethra, has called for increased efforts on the part of the bladder, the continuance of

which gives rise to an extraordinary augmentation in the thickness of its muscular coat.

363. Thus we see that the property of Irritability is a vital endowment peculiar to muscular tissue, and dependent for its existence upon due nutrition of that tissue; that it may be called into exercise by certain stimuli, applied either to the muscle itself, or to the nerve supplying it, provided that the muscle be also permeated with oxygen; that it may be exhausted by repeated stimulation, but is then recovered by rest, provided that there be no obstacle to the nutrition of the muscle; that the nutrition of the muscle is impaired by continued repose, and that its irritability diminishes in the same proportion; that the nutrition is increased by frequent use, and that the power of the muscle then augments in like degree; and finally that the departure of muscular power, which ensues upon the general death of the system, is dependent in part upon the cessation of the supply of oxygen, and in part upon changes in the composition of the muscle itself, which are no longer compensated by the functions that keep it in its normal condition during life.—The rapidity of these changes is the greatest in warm-blooded animals, in which also the muscular irritability is most dependent upon the presence of oxygen in the muscular substance; consequently the irritability departs after death much more speedily in these, than in cold-blooded animals.

364. We have now to consider that other form of contractility, which produces a *constant* tendency to contraction in the Muscular fibre, but which is so far different from simple elasticity, that it abates after death and before the commencement of decomposition. This *Tonicity* manifests itself in the retraction which takes-place in the ends of a living muscle when it is divided; the retraction being permanent, and greater than that of a dead muscle. It also shows itself in the permanent flexure of joints, when, by paralysis of the extensors, the tonic contraction of the flexors is not antagonized. In the healthy state, it would seem as if the tonicity of the several groups of muscles was so adjusted as to be in mutual counterpoise; but the balance is destroyed, when, in consequence of paralysis, or of impaired nutrition from other causes, the tonicity of one set is weakened. This is the case, for example, in lead palsy; in which the extensors of the fore-arm and hand lose their power, so that the tonic contraction of the flexors keeps the fingers constantly bent upon the palm. It would seem, however, that the tonicity of the flexors is usually greater than that of the extensors; as the former predominate, when all are equally withdrawn from the control of the nervous system in profound sleep.

365. The Tonicity is much greater, relatively to the amount of irritability, in the non-striated, than in the striated fibre; and it is particularly remarkable in the fibrous coat of the arteries, in which it is difficult to procure any decided indication of irritability by the

application of stimuli. It is by this [illegible]nicity of the walls of the arteries, that they are kept in a state of [illegible]onstant moderate contraction upon their contents; and that, w[illegible]n they are emptied, they contract until the tube is nearly obliterated. If its amount be too great (as sometimes happens) the artery approaches the condition of a rigid tube; which, as will be shown hereafter (§ 583), is unfavourable to the regularity of the flow of blood through it, though the rate is increased. On the other hand, if it be unduly diminished, the circulation is retarded, by the tendency of the arterial walls to yield too much to the pulse-wave.

366. This property is very greatly affected by temperature; being diminished by warmth, and increased by cold. Thus when an artery is exposed to the air for some time, the lowering of its temperature occasions its contraction to such an extent, that its tube may be almost obliterated. And in the operation of 'crimping' fish, immersion of the body in cold water, after the muscles have been divided, increases their tonic contraction, and thus augments that firmness of their substance which it is the object of this operation to produce.

367. The *Rigor Mortis*, or death-stiffening of the muscles, is probably to be regarded as a manifestation of this property, occurring after all the Irritability of the muscles has departed, but before any putrefactive change has commenced. This phenomenon is rarely absent; although it may be so slight, and may last for so short a time, as to escape observation. The period which elapses before its commencement is as variable as its duration; and both seem to be dependent upon the vital condition of the system at the time of death. When it has been weakened or depressed by previous disease, the irritability of the muscles speedily departs; and the stiffening comes-on early, and lasts but a short time. Thus, after death from Typhus, the limbs have been sometimes known to stiffen within 15 or 20 minutes. On the other hand, when the general vigour of the system has not been previously impaired, and death has resulted from some sudden cause, the irritability of the muscles is of longer duration, and their stiffening is consequently deferred. The commencement of the rigidity usually takes-place within seven hours after death; but twenty or even thirty hours may elapse before it shows itself. Its general duration is from twenty-four to thirty-six hours; but it may pass-off much more rapidly, or it may be prolonged through several days. It affects all the muscles composed of the striated fibre with nearly the same intensity; except that the flexors usually contract more strongly than the extensors (as in sleep), the fingers being closed upon the palm, the hand bending on the fore-arm, and the lower jaw being drawn firmly against the upper. And it even manifests itself in muscles that have been thrown out of use by paralysis, provided that their nutrition has not been seriously impaired.

368. This tonic contraction, however, is most remarkably manifested in the non-striated fibre; and especially in the heart and blood-vessels. As soon as the muscular walls of the several cavities lose their irritability, they begin to contract forcibly upon their contents, and thus become stiff and firm, although they were previously flaccid. In this manner, the ventricles of the heart, which are the first parts to lose their irritability, become rigid and contracted within an hour or two after death; and usually remain in that state for ten or twelve hours, sometimes for twenty-four or thirty-six, then again becoming relaxed and flaccid. This rigid contracted state of the heart, in which the walls are thickened and the cavities diminished, was formerly supposed to be a result of disease, and was termed concentric hypertrophy; but it is now known to be the natural condition of the organ, at the period when the rigor mortis occurs in it.—The contraction of the arterial tubes is so great, as to produce for the time a great diminution in their calibre; and this doubtless contributes to the passage of the blood from the arterial into the venous system, which almost invariably takes-place within a few hours after death. The arteries then enlarge again and become quite flaccid, their tubes being emptied of their previous contents; and it was from this circumstance, that the ancient physiologists were led to imagine that the arteries are not destined to carry blood, but air.

369. As soon as the Rigor Mortis departs, the muscles pass into a state of decomposition; in fact, it is by the commencement of decomposition, that the cessation of this vital property is occasioned. Thus we may regard the Rigor Mortis as the last act of the Muscular Contractility: and in this respect it corresponds with the coagulation of the blood, which also is the closing act of its life, when it is drawn from the living body, or has ceased to circulate (§ 184). There are, indeed, many remarkable points of correspondence between the two phenomena; which have induced some physiologists to believe, that *rigor mortis* is in fact nothing else than the coagulation of the blood in the muscles. It has been shown by Mr. Bowman, however, that the stiffening of the muscles after death is due to the permanent contraction of their component fibres, and that the coagulation of the blood can have nothing to do with it. Nevertheless, this contraction may be considered as being, for the muscular fibre, a phenomenon of very much the same kind as the coagulation of the fluid fibrin of the blood,—especially resembling that subsequent contraction of the clot, which takes place gradually within a few hours after its separation. The causes which prevent the coagulation of the blood after death (§ 187), usually prevent also this last manifestation of the tonicity of the muscles; their vitality being completely destroyed, like that of the blood, by sudden and powerful shocks operating on the nervous system, or by the complete exhaustion consequent upon violent and

long-continued exertion, as when animals are run to death. And again, the tonicity of muscles survives the freezing process, manifesting itself by contraction and rigidity in a muscle that has been frozen immediately after death and is subsequently thawed; just as the peculiar properties of the fibrin of the blood cause its coagulation upon being thawed, if it have been frozen immediately upon being drawn from the vessels.

370. The power by which the elements of Muscular fibre are caused to approach one another in the exercise of their Contractility, differs from any other with which we are acquainted. Its complete dependence upon the life of the tissue is remarkably shown by the fact (ascertained by Valentin), that, after the cessation of the irritability, the muscles *tear* with a far less weight than they were previously able to *draw* when excited by galvanism; so that their contractile force is much greater than that which the simple cohesiveness of the tissue can sustain. Moreover, it has been shown by the experiments of Schwann, that the contractile force is greatest, when the muscle is most extended; so that, with the same stimulus, it can overcome a greater resistance by its contraction when it has been previously stretched to its full length, than it can when it has been already in part shortened by the exercise of its contractile force. The power diminishes progressively with the further shortening of the muscle; until at last no further contraction can be produced by any stimulus, the extreme limit having been reached. Hence it seems as if the contractile force of Muscles differs completely from such other forms of Attraction as those of Gravitation, Electricity, &c.; since it is the universal law of *their* operation, that the force *increases*, in proportion to the decrease between the squares of the distances between the attracting bodies; whilst, in the case of muscle the force *decreases*, in proportion as the distance between the attracting particles decreases. But it is to be remembered that the law of attraction just quoted supposes the particles to be quite free to approach one another; and this they obviously are not in the contraction of a muscle, since the approach cannot take place without a change of position between the solid and the fluid elements (§ 354). Hence it is difficult, if not impossible, to discover the law, which shall truly express the nature of the attraction between the ultimate particles of Muscle at different distances; though the law discovered by Schwann expresses the force actually developed at the different stages of muscular contraction.

371. It has been ascertained by the researches of MM. Becquerel and Breschet, that the temperature of a muscle rises, when it is thrown into energetic contraction. The increase is ordinarily but about 1° Fahr.; but it may amount to twice as much, if the same muscle be kept in action for some time, as in the exercise of sawing. Two causes may be assigned for this increase. It may depend upon the chemical changes which take-place in the Muscle, as a necessary

condition of the production of its force (§ 361); or it may be the result of the friction taking-place between its different parts, during the constant interchange of their actions (§ 356). Perhaps both these causes concur in producing the effect.

372. The *Nervous System*, taken as a whole, is the instrument of all those operations which peculiarly distinguish the Animal from the Plant; and it serves many additional purposes, connected with the Organic or Vegetative functions, which the peculiar arrangements of the Animal body involve. Wherever a distinct Nervous System can be made-out (which has not yet been found possible in the lowest Animals), it consists of two very different forms of structure, the presence of both of which, therefore, is essential to our idea of it as a whole. We observe, in the first place, that it is formed of *trunks*, which are distributed to the different parts of the body, especially to the muscles and to the sensory surfaces; and of *ganglia*, which sometimes appear merely as knots or enlargements on these trunks, but which, in other cases, have rather the character of central masses, from which the trunks proceed. Now it is easily established by experiment, that the *active powers* of the nervous system reside in the *ganglia*, and that the *trunks* serve merely as *conductors* of the influence, which is to be propagated towards or from them. For if a trunk be divided in any part of its course, all the parts to which the portion thus cut-off from the ganglion is distributed, are completely paralysed; that is, no impression made upon them is felt as a sensation, and no motion can be excited in them by any act of the mind. Or if the substance of the ganglion be destroyed, all the parts which are exclusively supplied by nervous trunks proceeding from it, are in like manner paralysed. But if, when a trunk is divided, the portion still connected with the ganglion be pinched, or otherwise irritated, sensations are felt, which are referred to the points supplied by the separated portion of the trunk; which shows that the part remaining in connexion with the ganglion is still capable of conveying impressions, and that the ganglion itself receives these impressions and makes them felt as sensations. On the other hand, if the separated portion of the trunk be irritated, motions are excited in the muscles which it supplies; showing that it is still capable of conveying the motor influence, though cut-off from the usual source of that influence.

373. When we minutely examine the trunk of a nerve, we find that it is composed, in the first place, of a *Neurilemma* or nerve-sheath, consisting of areolar tissue; the office of which is evidently that of protecting the nerve-tubes, and of isolating them from the surrounding structures, at the same time that it allows blood-vessels to pass into the interior of the trunk. From the interior of the neurilemma, thin layers of areolar tissue pass into the midst of the enclosed bundle of nervous fibres; separating it

into numerous smaller fasciculi, which are thus bound together and supplied with blood-vessels. The capillaries are distributed very much on the same plan as those of Muscular tissue (Fig. 70); the network being composed of straight vessels which run along the course of the nerve between the nerve-tubes, and which are connected at intervals by transverse vessels.—When the neurilemma has been removed, and the trunk has been separated into its component fasciculi, we may still further subdivide the fasciculi themselves, by careful dissection, until we arrive at the ultimate Nervous Fibre, which is the essential element of the structure. Two forms of this fibre exist in the nerves of higher animals, bearing a considerable analogy to the two forms of the Muscular fibre: one being known as the *tubular;* whilst the other, which seems to be in a state of less complete development, is distinguished as the *gelatinous*. These require a separate description.

374. The Nervous fibre, in its most complete form, is distinctly tubular. It is composed externally of a very delicate transparent membrane, which is apparently quite homogeneous; this is obviously analogous to the myolemma of the Muscular fibre, and serves, like it, to isolate the contained substance most completely from surrounding structures. This membranous tube is not penetrated by blood-vessels, nor does it branch or anastomose with others; and there is reason to believe it to be continuous from the origin to the termination of the nervous trunk. Within the tube is a hollow cylinder, of a material known as the *White substance of Schwann*, which differs in composition and refracting power from the matter that occupies the centre of the tube, and of which the outer and inner boundaries are marked-out by two distinct lines. And the centre or axis of the tube is occupied by a transparent substance, which is termed the *axis-cylinder*. There is reason to believe that this last is the essential component of the nervous fibre; and that the hollow cylinder which surrounds it, serves, like the external investment, chiefly for its complete isolation. The whole of the matter contained in the tubular sheath is extremely soft; yielding to very slight pressure. The tubular sheath itself varies in density in different parts; being stronger in the nervous trunks, than in the substance of the brain and spinal cord. In the former, it is not difficult to show that the regular form of the nerve-tube is a perfect cylinder; though a little disturbance will cause an alteration in this,—a small excess of pressure in one part forcing the contents of the tube towards another, where they are more free to distend it, and thus producing a swelling. The greater delicacy of the tubular sheath in the latter, causes this result to take-place with yet more readiness; so that a very little manipulation, exercised upon the fibres of the brain and spinal cord, or on those of special sense, occasions them to assume a *varicose* or beaded appearance, which, when first observed by Ehrenberg, was thought to be characteristic

of them. When the fibres of these parts, however, are examined without any such preparation, they are found to be as cylindrical as the others.—The diameter of the tubuli is usually between 1-2000th and 1-4000th of an inch. Sometimes, however, it is as much as 1-1500th; and occasionally as little as 1-14,000th. They are larger in the nerve-trunks than in the brain; and they diminish in the latter as they approach the cortical substance. The fibres of the nerves of special sense are smaller than the average, in every part of their course.

375. The gelatinous fibres cannot be shown to consist of the same variety of parts as the preceding; no tubular envelope can be distinguished; and the white substance of Schwann seems wanting. They are flattened, soft, and homogeneous in their appearance, bearing a considerable resemblance to the unstriped Muscular fibres; and, like them, they contain numerous cell-nuclei, which are arranged with tolerable regularity. These nuclei are brought into view by acetic acid, which dissolves the rest of the fibre, leaving them unchanged. The gelatinous fibres are usually of smaller size than the tubular, their diameter averaging between the 1-6000th and the 1-4000th of an inch; and they sometimes show a disposition to split into very delicate fibrillæ. Being of a yellowish-grey colour, they have been sometimes distinguished as the *grey* fibres.—These two classes of fibres have been supposed to be essentially distinct in character and office; the 'tubular' having been regarded as ministering to the *Animal* functions of sensation and motion; and the 'gelatinous' as connected with the *Organic* or nutritive operations. The facts which will be presently stated (§ 388) regarding their origin, however, as well as their joint existence in almost every nerve, are decidedly adverse to this view; and we shall find reason to consider them as differing chiefly in grade of development. Indeed it appears that the very same fibre may be 'tubular' in one part of its course and 'gelatinous' in another.

376. The Nerve-fibres ordinarily appear to run continuously, from one extremity of a nervous cord to the other, without any union or anastomosis; each ultimate fibre probably having its distinct office, which it cannot share with another. The fasciculi, or bundles of fibres, however, occasionally intermix and exchange fibres with each other; and this interchange may take-place among either the fasciculi of the same trunk, or among those of different trunks. Its object is evidently to diffuse among the different branches the endowments of a particular set of fibres. Thus we shall hereafter see that, in all the Spinal Nerves of Vertebrata, one set of roots ministers to sensation, and another to motion; the sensory fibres are *principally* distributed to the skin, and the motor fibres to the muscles; but every branch contains both sensory and motor fibres, which are brought together by the interlacement of those connected with both sets of roots. In the head, we have some nervous trunks

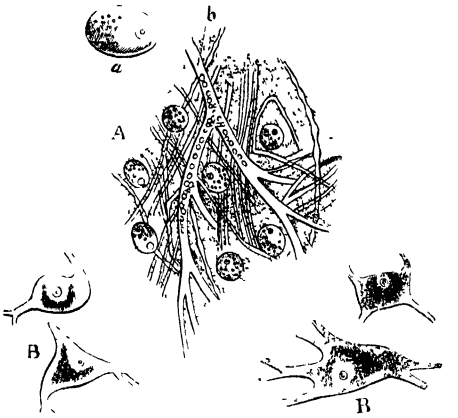
which have sensory roots alone; and others which have motor roots only; these in like manner acquire each other's functions in some degree by an interchange of filaments,—the sensory trunk receiving motor fibres, and the motor trunk receiving sensory fibres. An interchange of this kind, upon a very extensive scale, takes-place between the Cerebro-spinal system, whose ganglionic centres are the brain and spinal cord, and the Sympathetic system, whose centres consist of a number of scattered ganglia. The former sends a large number of fibres into the latter, by the twigs of communication near the origins of the Spinal nerves, as well as by their connecting branches; whilst the latter sends a smaller number of fibres into the former, these being chiefly of the gelatinous kind.

377. Sometimes we find the fasciculi of several distinct trunks united into an extensive plexus; one object of which appears to be, to give a more advantageous distribution to fibres which all possess corresponding endowments. Thus the *brachial* plexus mixes together the fibres arising by five pairs of roots, on either side, from the spinal cord; and sends off five principal trunks to supply the arm. Now if each of these trunks had arisen by itself, from a distinct segment of the spinal cord, so that the parts on which it is distributed had only a single connexion with the nervous centres, they would have been much more liable to paralysis than they are. By means of the plexus, every part is supplied with fibres arising from each of the five segments of the spinal cord; and the functions of the whole must, therefore, be suspended, before complete paralysis of any part could occur, from a cause which operates above the plexus. This may be experimentally shown on the Frog, whose crural plexus is formed by the interlacement of the component fasciculi of three trunks on each side; for section of the roots of one of these produces little effect on the general movements of the limb; and even when two are divided, there is no paralysis of any of its actions, all being weakened in nearly an equal degree.—It is probable, however, that (as suggested by Dr. Gull) another use of this arrangement is to bring *groups of muscles* into relation with the different segments of the Cord, in such a mode that their actions may be combined and harmonized. We shall hereafter (CHAP. XII.) find reason to believe, that the Will does not at once act through the nerves upon the muscles; but that it plays (so to speak) upon the Spinal cord, each segment of which has its own particular endowments, and ministers to a particular set of movements. And thus, the greater the variety of movements which any part is destined to perform, the more complicated will be the nervous plexus by which its muscles are connected with the centres of motion.

378. The second primary element of the Nervous System, without which the fibrous portion would seem to be totally inoperative, is composed of nucleated cells, containing a finely granular substance,

and lying somewhat loosely in the midst of a minute plexus of blood-vessels (Fig. 72, A). Their normal form may be regarded as globular (hence they have been termed *nerve-* or *ganglion-globules*); but this is liable to alteration from the compression they suffer, so that they become oval or polygonal. The most remarkable change

Fig. 72.*



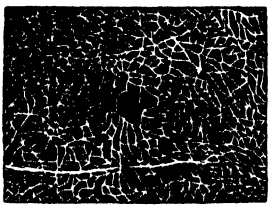
of form, however, which they undergo, is by an extension into one or more long processes, giving them a *caudate* or a *stellate* aspect (B, B). These processes are composed of a finely-granular substance, resembling that of the interior of the vesicle, with which they seem to be distinctly continuous; and if traced to a distance, they are frequently found to become continuous with the axis-cylinders of the nerve-tubes. As a general rule, according to Prof. Kolliker, only one nerve-tube is connected with each ganglion-cell; but this rule is not without its exceptions, especially among the lower animals. The other processes seem to inosculate with those of other cells, so as to establish a direct communication between them. In some instances, again, the ganglionic cell comes into relation with the fibre, not by sending out a prolongation which is continuous with it, but by being received into the cavity of the fibre (so to speak) by an extension of

* Primitive fibres and ganglionic globules of Human Brain, after Purkinje.—A, ganglionic globules lying amongst varicose nerve-tubes and blood-vessels, in substance of optic thalamus; *a*, globule more enlarged; *b*, small vascular trunk:—B, B, globules with variously-formed pedunces, from dark portion of crus cerebri. 350 Diam.

the tubular wall over it. In other cases, moreover, the fibres merely pass around and amongst the ganglionic cells, without coming into direct connection with them; and when this is the case, the ganglionic cells retain their simply-globular character.—Besides the finely-granular substance just mentioned, these cells usually contain a collection of pigment-granules, which give them a reddish or yellowish-brown colour: this, however, is frequently absent, especially among the lower animals.—The size of the vesicles is liable to great variation; the globular ones are usually between 1-300th and 1-1250th of an inch in diameter.

379. The vesicles just described are aggregated together in masses of variable size; and are in some degree held together by the plexus of Blood-vessels (Fig. 73), in the midst of which they lie. They are sometimes imbedded in a soft granular substance, which adheres closely to their exterior and to their processes; this is the case in the outer part of the cortical substance of the human brain. In other instances, each cell is enclosed in a distinct envelope, composed of smaller cells closely adherent to each other and to the contained cell; such an arrangement is common in the smaller ganglia, and in the inner portion of the cortical substance of the brain.—The substance which is made-up of these peculiar cells, of the plexus of the blood-vessels in which they lie, and of the granular matter that is disposed amongst them, is altogether known as the *cineritious* or *grey* substance; being distinguished by its colour, in Man and the higher animals at least, from the *white* substance (composed of nerve-tubes) of which the trunks of the nerves, as well as a large part of the brain and spinal cord, are made-up. But this distinction is by no means constant; for the grey colour, which is partly due to the pigment-granules of the cells, and partly to the redness of the blood in the vessels, is wanting in the Invertebrata generally, and is not characteristically seen in the classes of Fishes and Reptiles. Moreover, when the ganglionic substance exists in small amount, even in Man, its colour is not sufficiently intense to serve to distinguish it; and, as we have already seen, there are nerve-fibres which possess a greyish hue. The real distinction evidently lies in the *form* of the ultimate structure, which is *fibrous* in the one case, and *cellular* or *vesicular* in the other; and these

Fig. 73.*

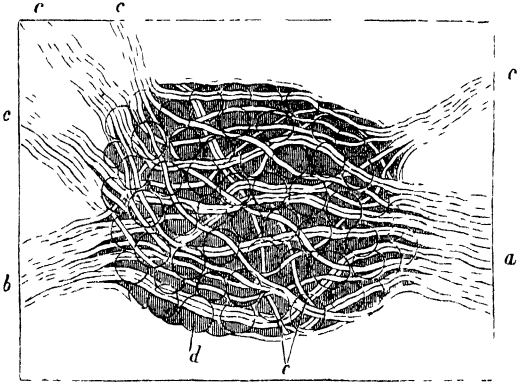


* Capillary network of Nervous Centres.

terms will be henceforth used to characterize the two kinds of Nervous tissue which have been now described.

380. A *ganglion*, then, essentially consists of a collection of nerve-vesicles or ganglion-globules, interspersed among the nerve-fibres; and it is in the presence of the former, that it differs from a *plexus*, which it frequently resembles in the arrangement of the latter. When a nerve enters a ganglion, its component fibres separate and pass through the ganglion in different directions, so as to be variously distributed among the branches which pass out of it (Fig. 74); coming, in their course, into relation with the vesicular

*Fig. 74.**



matter which occupies the interior of the ganglion, in one or more of the modes already specified (§ 378). Some of the fibres may terminate in the cells of the ganglion, and new ones may originate in them; so that there is no constant correspondence between the number of fibres which enter a ganglion, and of those which pass out of it.—The only exception to the general fact, that the vesicular matter occupies the centre of the ganglia, occurs in the brain of Vertebrata, in which it is chiefly disposed on the exterior, forming the *cortical* envelope. The reason for this variation is probably to be found in the very large amount of this substance, which the brain of the higher Vertebrata contains; and in the necessity of the

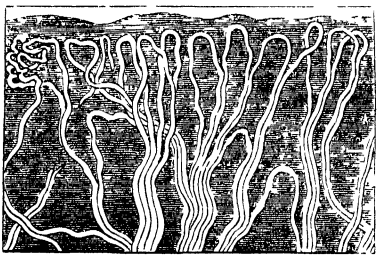
* Dorsal ganglion of Sympathetic nerve of Mouse:—*a*, *b*, cords of connection with adjacent sympathetic ganglia; *c*, *c*, *c*, *c*, branches to the viscera and spinal nerve; *d*, ganglionic globules or cells; *e*, nervous fibres crossing the ganglion.

free access of blood-vessels to it, which is provided-for by a great extension of its surface beneath the investing vascular membrane (pia mater), more readily than it could be in any other mode.

381. But the vesicular matter is not found in the *central* masses only of the Nervous system; for it presents itself also at those parts of the *surface* or *periphery*, which are peculiarly destined to receive the impressions that are to be conveyed to the central organs. Thus on the expansion of the optic nerve which forms the retina, there is a distinct layer of ganglionic corpuscles or nerve-cells, with a minute plexus of vessels, possessing all the essential characters of the vesicular substance of the brain; and something of the same kind has been seen in connection with the corresponding expansions of the olfactive and auditory nerves. Moreover, the study of the history of the development of these organs has shown, that the vesicular matter of the retina is an offshoot (so to speak) from that of the optic ganglion, that of the labyrinth of the ear being in like manner an offshoot from that of the auditory ganglion. Thus it is obvious that the fibres of the connecting nerve are interposed between the cells of the peripheral and those of the central organs, for the sake of preserving that connection between them which would otherwise have been interrupted; and that the vesicular matter is the active agent in the *origination* of those changes which take-place as a consequence of sensory impressions, whilst for the *conduction* of such changes, the fibrous structure is alone required.

382. The ultimate distribution of the nerve-fibres in the skin and tongue, however, has not been so clearly made-out, nor can their relation to cells be distinctly traced. These fibres are distributed, for the most part, to the papillæ, in some of which they appear to form loops (Fig. 75), accompanied by similar loops of

Fig 75 *



* Distribution of the Tactile Nerves at the surface of the lip; as seen in a thin perpendicular section of the Skin.

blood-vessels (Fig. 76); but though such loops can be seen in the conical papillæ of the tongue, they cannot be discerned in the fungiform papillæ, the continuity of their nerve-fibres not being distinguishable near their apices. Here, however, the history of the development of the nervous plexuses in the skin s to indicate that the fibres may be considered as commencing in a peripheral ganglionic expansion; for it has been shown by the observations of Prof. Kölliker upon the tail of the tadpole, that the nervous plexuses are formed in the same manner as the capillary net-work; namely, by the inosculation of the prolongations of radiating cells, whose centres are at a considerable distance from each other. Hence it is probable that cell-nuclei, or some equivalent centres of force, remain in connection with the peripheral nerve-fibres of the skin and tongue, as with ...se of other sensory surfaces. Sometimes the ultimate plexuses seem to be formed in the Skin, as in Muscle, by the subdivision of the primitive fibres (§ 341).

Fig. 76.*



383. We have now to speak briefly of the Chemical Composition of the Nervous matter;—a consideration which will be presently shown to be of much importance. As formerly remarked (§ 7), the vital activity of a tissue is usually greater, as the proportion of its solid to its fluid contents is less; and this rule holds-good most strikingly in regard to the Nervous substance, the vital activity of which is far greater than that of any other tissue, and the solid matter of which usually constitutes no more than a fourth, and occasionally does not exceed an eighth, of its entire weight. The proportion of water is greatest in infancy and least in middle life; and it has been observed to be under the average in idiots. Of the solid matter of the brain, about a third consists of an albuminoid substance, which is probably the material of the membrane of the tubuli, as well as of the tissue that connects them.—It is chiefly with the Fatty matter, which constitutes about a third of the solid substance, that the attention of Chemists has been occupied. This is stated by M. Fremy (one of the most recent analysts) to contain, besides the ordinary fatty matters, and Cholesterine or biliary fat, two peculiar fatty acids, termed the Cerebric and the Oleo-phosphoric. *Cerebric* acid, when purified, is white, and presents itself in crystalline grains. It contains a small proportion of Phosphorus; and

* Capillary net-work at margin of lips.

differs from the ordinary fatty matters in containing Nitrogen, as also in containing twice their proportion of oxygen. *Oleo-phosphoric* acid is separated from the former by its solubility in ether; it is of a viscid consistence; but when boiled for a long time in water or alcohol, it gradually loses its viscidity, and resolves itself into a pure oil, which is elaine, while phosphoric acid remains in the liquor. The proportion of phosphorus in the brain is considerable; being from 8 to 18 parts in 1000 of the whole mass, or from 1-20th to 1-30th of the whole solid matter. It seems to be unusually deficient in the brain of idiots.—The remaining third and sometimes more, is composed of a substance related to albumen in composition, of which part seems to be in a state of solution, and the rest in a state of fine division. It is curious that (according to Lehmann) the substance which forms the axis-cylinder of the tubular nerve-fibres, is allied to the syntonin of muscle in its reactions with acetic acid and with the concentrated mineral acids and alkalies. In the white substance of Schwann, on the other hand, fat seems to predominate.

384. Various circumstances lead to the belief, that the Nervous tissue, during the whole period of active life, is continually undergoing changes in its substance by decay and renewal. We know that, after death, it is one of the first of all the animal tissues to exhibit signs of decomposition; and there is no reason to suppose that this tendency is absent during life. Hence for the simple maintenance of its normal character, a considerable amount of nutritive change must be required. But many circumstances further lead to the conclusion, that, like all other tissues actively concerned in the vital operations, Nervous matter is subject to a *waste* or *disintegration*, which bears an exact proportion to the activity of its operations;—or, in other words, that every act of the Nervous system involves the death and decay of a certain amount of Nervous matter, the replacement of which will be requisite in order to maintain the system in a state fit for action. We shall hereafter see that there are certain parts of the Nervous system, particularly such as put in action the respiratory muscles, which are in a state of unceasing, though moderate, activity; and in these, the constant nutrition is sufficient to repair the effects of the constant decay. But those parts which operate in a more powerful and energetic manner, and which therefore waste more rapidly when in action, need a season of rest for their reparation. Thus a sense of fatigue is experienced, when the mind has been long acting through its instrument—the brain; indicating the necessity for rest and reparation. And when *sleep*, or cessation of the cerebral functions, comes on, the process of nutrition takes-place with unchecked energy, counterbalances the results of the previous waste, and prepares the organ for a renewal of its activity. In the healthy state of the body, when the exertion of the nervous system by day does not exceed

that which the repose of the night may compensate, it is maintained in a condition which fits it for constant moderate exercise; but unusual demands upon its powers,—whether by the long-continued and severe exercise of the intellect, by excitement of the emotions, or by the combination of both in that state of *anxiety* which the circumstances of man's condition too frequently induce,—occasion an unusual waste, which requires, for the complete restoration of its powers, a prolonged repose.

385. There can be no doubt that (from causes which are not known) the amount of sleep required by different persons, for the maintenance of a healthy condition of the nervous system, varies considerably; some being able to dispense with it, to a degree which would be exceedingly injurious to others of no greater mental activity. Where a prolonged exertion of the mind has been made, and the natural tendency to sleep has been habitually resisted by a strong effort of the will, injurious results are sure to follow. The bodily health breaks-down, and too frequently the mind itself is permanently enfeebled. It is obvious that the nutrition of the Nervous system becomes completely deranged; and that the tissue is no longer formed in the manner requisite for the discharge of its healthy functions.

386. As the amount of Muscular tissue that has undergone disintegration, is represented (other things being equal) by the quantity of urea in the urine, so do we find that an unusual waste of the *nervous* matter is indicated by an increase in the amount of *phosphatic* deposits. No others of the soft tissues contain any large proportion of phosphorus; and the marked increase in these deposits, which has been continually observed to accompany long-continued *wear* of mind, whether by intellectual exertion, or by anxiety, can scarcely be set-down to any other cause. The most satisfactory proof is to be found in cases in which there is a periodical demand upon the mental powers—as, for example, among clergymen, in the preparation for, and discharge of, their Sunday duties;—this being almost invariably followed by the appearance of a large quantity of the phosphates in the urine. And in cases in which constant and severe intellectual exertion has impaired the nutrition of the brain, and has consequently weakened the mental power, it is found that any premature attempt to renew the activity of its exercise, causes the re-appearance of the excessive phosphatic discharge, which indicates an undue waste of nervous matter.

387. As the disintegration of the Nervous System is thus proportional to its exercise, so must its reparation make a corresponding demand upon the nutritive processes. And accordingly we find that it is very copiously supplied with blood-vessels; and that the amount of food appropriated to its maintenance in an active condition, is very considerable.. This we know from the fact, that persons of active minds but sedentary bodily habits, commonly

require nearly as much food as those in whom the waste of the Muscular system is greater and that of the Nervous system less, in virtue of their bodily activity and the less energetic operation of their minds.

388. The nerve-fibres appear to originate, according to the observations of Prof. Kölliker, in cells which become fusiform by elongation (§ 193), and which then coalesce at their extremities; and these seem to increase, after the first formation of the trunks, by the longitudinal subdivision of fusiform cells which had not previously undergone complete metamorphosis into fibres, as well as by the development of cells *de novo*. The nuclei of the original cells may be frequently seen in the nerve-tubes at a later period, lying between their membranous walls and the substance deposited in their interior. The earliest condition of both forms of nerve-fibre appears to be precisely the same; but the *gelatinous* remains in a state nearly resembling this; whilst the tubular is developed into a higher form. Various gradations, indeed, may be traced between the two.—The vesicular matter appears to be in a state of continual change, as is the case with all cells whose functions are active. The appearances observed by Henle in the cortical substance of the brain lead to the belief, that there is as continual a succession of nerve-cells, as there is of epidermic cells; their development commencing at the surface, where they are most copiously supplied with blood-vessels from the investing membrane, and proceeding as they are carried towards the inner layers, where they come into more immediate relation with the fibrous portion of the nerve-structure. This change of place is probably due to the continual death and decay of the mature cells, where they are connected with the fibres; and the constant production of new generations at the external surface,—thus carrying the previously-formed cells inwards, in precisely the same manner that the epidermic cells are progressively carried outwards.

389. The *regeneration* of Nervous tissue that has been destroyed, takes-place very readily in continuity with that which is left sound. This may be more easily proved by the return of the sensory and motor endowments of the part whose nerves have been separated, than by microscopic examination of the reunited trunks themselves, which is not always satisfactory. All our knowledge of the functions of the nervous system leads to the belief, that *perfect continuity* of the nerve-tubes is requisite for the conduction of an impression of any kind, whether this be destined to produce motion or sensation; and various facts, well known to Surgeons, prove that such restoration may be complete. In the various operations which are practised for the restoration of lost parts, a portion of tissue removed from one spot is grafted, as it were, upon another; its original attachments are more or less completely severed,—frequently altogether destroyed,—and new ones are formed. Now

in such a part, so long as its original connections exist, and the new ones are not completely formed, the sensation is referred to the spot from which it was taken; thus when a new nose is made by partly detaching and bringing-down a piece of skin from the forehead, the patient at first feels, when anything touches the tip of his nose, as if the contact were really with his forehead. After time has been given, however, for the establishment of new connections with the parts into whose neighbourhood it has been brought, the old connections of the grafted portion are completely severed; and an interval then ensues, during which it frequently loses all sensibility; but after a time its power of feeling is restored, and the sensations received through it are referred to the right spot.—A more familiar case is the regeneration of Skin containing sensory nerves, which takes-place in the well-managed healing of wounds involving loss of substance. Here there must obviously be, not merely a prolongation of the nerve-tubes from the subjacent and surrounding trunks, but also a formation of new sensory papillæ.—A still more striking example of the regeneration of Nervous tissue, however, is to be found in those cases (of which there are now several on record), in which portions of the extremities that have been completely severed by accident, have been made to adhere to the stump; and have, in time, completely recovered their connection with the Nervous as with the other systems, as is indicated by the restoration of their sensory and motor endowments.—Of the degree in which the vesicular substance of the Nervous system may be regenerated, we have no certain knowledge; but there can be little doubt from the activity of its usual nutritive changes, that a complete reproduction may be effected in cases of loss of substance, where it can commence from a neighbouring mass of the same tissue.

390. We have now to inquire into the conditions under which the peculiar properties of the Nervous System are manifested in an active form; and it will first be desirable to explain, somewhat more in detail, the nature of the different operations to which it is subservient. These operations present themselves in their most complex form, in Man and the higher animals; but they may often be most satisfactorily studied in the lower. In the first place, when an *impression* is made upon any part of the surface of the body by mechanical contact, by heat, electricity, or any other similar agent,—or upon the organs of special sense (the eye and ear, the nose and tongue), by light or sound, by odorous or sapid bodies,—these impressions, in the healthy and wakeful state of the Nervous system, are *felt* as *sensations;* that is, the mind is rendered conscious of them. Now there can be no doubt that the mind is immediately influenced, not by the impression in the remote organ, but by a certain change in the condition of the brain, excited or aroused by that which has originated elsewhere. For if

the communication with the brain be cut-off, no impression on the distant parts of the nervous system is felt, notwithstanding that the mind remains perfectly capable of receiving it. The mind, then, is only rendered conscious of external objects, by the influence which they exert upon the *brain*, or upon a certain part of it, which, being the peculiar seat of sensation, is called the *sensorium*. Hence we recognize, in the process by which the mind is rendered conscious of external objects, three distinct stages;—first, the reception of the impression at the extremities of the sensory nerve; second, the conduction of the impression, along the trunk of the nerve, to the sensorium; third, the change excited by it in the sensorium itself, through which sensation is produced. Here, then, the change in the condition of the nervous system commences at the circumference, and is transmitted to the centre; and the fibres which are concerned in this transmission are termed *sensory*.

391. On the other hand, when an emotion, an instinctive impulse, or an act of the will, operates through the central organs to produce a muscular contraction, the first change is in the condition of the vesicular substance of those organs. The influence of this change is transmitted by the motor nerves to the muscles, among which they are distributed; and the desired movement is the result. Here, too, we have at least three stages;—first, the origination of the change by an impression acting on the central organ; second, the conduction of that change along the motor nerves; and third, the stimulation of the muscles to contraction. But the operation here commences at the centre; and the effects of the change in the brain are transmitted to the circumference, by a set of nervous fibres which are termed *motor*. The complete distinctness of these two classes of fibres was first established by Sir C. Bell. It is best seen in the nerves of the head, of which some are purely sensory, and others purely motor; but it may also be clearly proved to exist at the *roots* of the spinal nerves (although their *trunks* possess mixed endowments), the posterior being sensory, whilst the anterior are motor.

392. But although sensations can only be felt through the *brain*, and voluntary motions can only be produced by an action of the mind through the same organ, yet there are many changes in the animal body, wherein the nervous system is concerned, which yet do not involve the operation of the brain, being produced without our consciousness being necessarily excited, and without any act of the will, or even in opposition to its efforts. Of these actions, the spinal cord of Vertebrata, and its prolongation within the cranium, are the chief instruments; in the Invertebrate animals, they are performed by various ganglia, which are usually disposed in the neighbourhood of the organs to which they minister. If the spinal cord of a Frog be divided in its back, above the crural plexus, so as entirely to cut-off the nerves of the lower extremities from connec-

tion with the brain, the animal loses all voluntary control over these limbs, and no sign of pain is produced by any injury done to them. But they are not thereby rendered motionless; for various stimuli applied to the limbs themselves will cause movements in them. Thus if the skin of the foot be pinched, or if a flame be applied to it, the leg will be violently retracted. Or, if the cloaca be irritated by a probe, the feet will endeavour to push away the instrument. We have no reason hence to believe that the animal feels the irritation, or intends to execute these movements in order to escape from it; for motions of a similar kind are exhibited by men who have suffered injury of the lower part of the spinal cord, and who are utterly unconscious, either of the irritation which their limbs receive, or of the actions which they perform.

393. We are not to suppose, however, that the stimulus acts at once upon the muscles, without the nervous system being concerned at all; throwing them into contraction by its direct influence. For it is quite certain that unless the nervous trunks remain continuous with the spinal cord, and unless the part of the spinal cord with which they are connected remains sound (although cut-off from connection with the parts above, and with the brain), no action will result. If the trunks be divided, or *either* of the roots by which they are connected with the spinal cord be severed, or the lower portion of the spinal cord itself be injured, no stimulation will cause the muscular movements just described. A very good example of this necessity for the completeness of the nervous trunks which convey impressions *to* and *from* the central organ, is found in the movements of the iris concerned in the contraction and dilatation of the pupil. Here the stimulus of light upon the retina gives rise to a change in the condition of the optic nerve; which, being transmitted to a certain portion of the encephalon with which that nerve is connected, excites there a motor impulse; and this impulse, being conveyed through a distinct nerve (a branch of the third pair) to the iris, occasions contraction of the pupil. Every one knows that this adjustment of the size of the pupil to the amount of light, is effected without any exertion of the will on his own part, and even without any consciousness that it is taking place. It is performed, too, during profound sleep; when the influence of light upon the retina excites no consciousness of its presence,—when no sensation, therefore, is produced by it.

394. The class of actions thus performed, is termed *reflex;* and we see that every such action involves the following series of changes. In the first place, an impression is made upon the extremity of a nerve, by some external agent; just as when sensation is to be produced. Secondly, this impression is transmitted by a nervous trunk to the spinal cord in Vertebrata, or to some ganglionic mass which answers to it in the Invertebrata. But instead of being communicated by its means to the mind, and

becoming a sensation, it immediately and necessarily executes a motor impulse; which is *reflected* back as it were to certain muscles, and, by their contraction, gives rise to a movement. We shall hereafter see, that nearly all those movements in the animal body, which are immediately connected with the maintenance of the organic functions,—such as those of respiration, deglutition (or swallowing), the expulsion of the fæces, urine, fœtus, &c.—are performed in this manner.

395. Now there is strong reason to believe that the changes which take-place in the nervous trunks are of the same nature, whatever may be the source from which they proceed,—whether, for example, the movement be simply-reflex, whether it proceed from a mental emotion, or whether it be executed in obedience to an act of the will. It was formerly supposed that all the *afferent* or *centripetal* fibres pass-up to the Brain, and that all the *efferent* or *centrifugal* fibres pass-down from the same organ; the Spinal Cord being looked-upon as little else than a bundle of nerves. It is now known, however, that a large proportion of the fibres of any trunk terminate in the central organ to which that trunk at first proceeds; and that the Spinal Cord may be considered as a series of such ganglionic centres, each receiving the afferent fibres, and giving origin to the efferent, of its own segment. So, again, the special sensory nerves, the olfactive, optic, auditory, and gustative, terminate in their own ganglionic centres, which lie at the base of the brain in immediate connection with the summit of the spinal cord, and which are quite independent of the cerebrum. The apparatus for receiving impressions, and for originating motions, is thus complete in itself; and the addition of the cerebrum does not make any essential difference in its operations, save that this sensori-motor apparatus (as it may be termed) is made to act through its means as the agent of the mind, in addition to its functions as the instrument of the automatic movements. We shall hereafter see (CHAP. XII.), that the difference between Instinct and Intelligence is closely connected with the development of the cerebrum; but that this organ, even in that highest grade of development which it possesses in Man, has no other connection with the sensory organs than that which it acquires through its relation with the sensory ganglia, and has no more power of exciting muscular movement, than by playing (so to speak) upon the spinal cord, whose efferent fibres respond to its mandates, just as they would do to the stimulus of an impression primarily acting through that organ.

396. Of the mode by which the effects of changes in one part of the Nervous system are thus instantaneously transmitted to another, nothing whatever is known. There is evidently a strong analogy between this phenomenon, and the instantaneous transmission of the Electric power along good conductors; but the relation is much more intimate than this, for Electricity is capable of exciting Nerve

force, whilst, conversely, Nerve-force can excite Electricity. Thus, a very feeble galvanic current transmitted along a motor nerve, serves to excite contractions in the muscles supplied by it; and in like manner, a galvanic current transmitted along any of the sensory nerves, gives-rise to a sensation of the kind to which that nerve ministers. Moreover we shall hereafter see, that certain animals are capable of generating Electric power in a very remarkable manner (CHAP. X.); and that the nervous force is essentially concerned in this operation. But, on the other hand, it is quite certain that the influence transmitted along the nerves of the living body is something different from ordinary electricity; for all attempts to procure manifestations of electric changes in the state of nerves that are acting most energetically on muscles, have completely failed; and a nerve remains capable of conveying the influence of electricity, when it has been rendered unable to transmit the influence of the brain, as by tying a ligature around it, or by tightly compressing it between the forceps, which gives no interruption to the one agency, whilst it completely checks the other.—Notwithstanding, then, the strong *analogy* which exists between these two powers, we are not warranted in regarding them as *identical;* but they have towards each other that relation of reciprocity, which exists between Electricity and Heat, or between Electricity and Magnetism, each being convertible into the other in a certain definite ratio (§ 48).

397. It is more desirable, however, that we should understand the conditions under which the phenomena of the Nervous System take-place, than that we should spend much time in discussing the identity of its peculiar powers with any others in Nature. The *conducting* power of the nervous fibres appears to remain with little decrease for some time after death, especially in cold-blooded animals; for we can, by pinching, pricking, or otherwise stimulating the motor trunks, give-rise to contractions in the muscles supplied by them, exactly as during life. This power is much lessened by the influence of narcotics; so that if a nervous trunk be soaked in a solution of opium, belladonna, or other powerful narcotic, it ceases to be able to convey the effects of stimuli to the muscles, some time before the muscles themselves lose their contractile power. On the other hand, it seems to be exalted by various irritating influences; so that, when the nervous trunk has been treated with strychnia, or when it has been subjected to undue excitement in other ways, a very slight change is magnified (as it were) during its transmission, and produces effects of unusual intensity.

398. Now although the conducting power of the fibrous structure will continue for a time, after the circulation through it has ceased, the peculiar endowments of the vesicular substance, by which it *originates* the changes transmitted by the former, are *only* manifested when blood is moving through its capillaries. Thus if the circulation through the brain cease but for a moment, total insen-

sibility and loss of the power of voluntary motion immediately supervene. The brain is supplied with blood through four arteries, —the two internal carotids, and the two vertebrals; and by the communication of these with each other through the *circle of Willis*, the circulation will still be kept-up, if only one of them should convey blood into the cavity of the cranium. Hence it is necessary that the flow of blood should be checked through *all* of them, in order that the functions of the brain should be suspended; and the suspension is then complete and instantaneous. The best method of effecting this was devised by Sir Astley Cooper. He tied both the carotid arteries in a dog; which operation, for the reason just mentioned, did not produce any decided influence on the functions of the brain, the circulation being kept-up through the vertebrals. But upon compressing the latter, so as to suspend the flow of blood through them, *immediate* insensibility and loss of voluntary power were the result. When the compression was taken-off, the animal immediately returned to its usual state; and again became suddenly insensible, when the pressure was renewed. Although the functions of the Brain were thus suspended, those of the Spinal cord were not; as was shown by the occurrence of convulsive movements. But in the state called *Syncope*, or fainting, the suspension of the circulation, by a failure in the heart's action, causes an entire loss of power in both these centres; and a complete cessation of muscular movement is the result. This condition may come-on instantaneously, under the influence of powerful mental emotion, or of some other cause, which acts *primarily* in suspending the heart's action, and consequently in checking the circulation; the insensibility and loss of muscular power are *secondary* results, depending upon the suspension of the powers of the nervous centres consequent upon the cessation of the flow of blood through them.

399. The due activity of the vesicular nervous matter is not only dependent upon a sufficient supply of blood, but it requires that this blood should be in a state of extreme purity; for there is no tissue in the body whose functions are so readily deranged by any departure from the regular standard in the circulating fluid,—whether this consist in the alteration of the proportions of its normal ingredients, or in the introduction of other substances which have no proper place in it. One of the most fertile sources of disturbance in the action of the brain, consists in the retention of substances within the blood, which ought to be excreted from it. We shall hereafter see that three of the largest and most important organs in the body,—the lungs, the liver, and the kidneys,—have it for their special office, to separate from the circulating fluid the products of the decomposition which is continually taking-place in the body; and thereby to maintain its purity, and its fitness for its important functions. Now if these, from any cause, even partially fail in their office, speedy disturbance of the functions of the nervous

centres is the result. Thus if the lungs neither purify the venous blood from its impregnation with carbonic acid, nor restore to it the proper proportion of oxygen, the functions of the brain are seriously affected. The sensations become indistinct, the will loses its control over the muscles, giddiness and faintness come-on, and at last complete insensibility supervenes. Corresponding symptoms occur, though to a less serious degree, when the excretion of carbonic acid is but slightly impeded. Thus when a number of persons are shut-up in an ill-ventilated apartment, for a sufficient length of time to raise the proportion of carbonic acid in the air to 1 or 2 per cent., the continued purification of their blood by respiration is but insufficiently performed, for reasons which will be stated hereafter (CHAP. VIII.); and the carbonic acid accumulates in their blood, in a sufficient degree to produce headache and obtuseness of the mental powers.—Similar results take-place, as will be shown hereafter (CHAP. IX.), from the retention of the substances which ought to be drawn-off by the liver and kidneys; these, when they accumulate in even a trifling degree, produce torpor of the functions of the brain; and when their proportion increases, complete cessation of its power is the result, their action being precisely that of narcotic poisons. Various substances introduced into the blood may exert similar influences; depressing the activity of the vesicular substance of the nervous centres, and consequently producing torpidity, not merely in the reception of impressions and the performance of voluntary motions, but also in the mental operations generally.

400. On the other hand, various conditions of the blood, especially those depending on the presence of certain external agents, produce an undue energy in the functions of the nervous centres; which energy, however, is almost invariably accompanied by irregularity, or want of balance among the different actions. Of this we have a familiar example in the operation of Alcohol. Its first effect, when taken in moderate quantity, is usually to produce a simple increase in the activity of the cerebral functions. A further dose, however, occasions not merely an increase, but an irregularity; destroying that power of self-control which is so important a means of balancing the different tendencies in the healthy condition of the mind. And a still larger dose has the effect of a narcotic poison; producing diminution or suspension of activity in all the functions of the brain. In some persons, this is the mode in which the alcohol acts from the first, its stimulating effects being altogether wanting.—A similar activity is usually produced by the respiration of the Nitrous Oxide; which seems to increase all the powers of the mind, save that of self-control, which it diminishes; the individual, while under its influence, being the slave of his impulses, which act on his muscular system with astonishing energy. Very analogous to this, is the incipient stage of Mania; which is simply an undue energy of the cerebral functions, at first in some degree

under the control of the will, but afterwards increasing to an extent that renders the individual completely powerless over himself; and showing itself in the intensity of the sensations produced by external objects, in the vividness of the trains of thought (which, being entirely uncontrolled, succeed each other with apparent irregularity, though probably according to the laws of association and suggestion), and in the violence of the muscular actions. Such a state may continue for some time, without the intervention of sleep; but the subsequent exhaustion of nervous power is proportioned to the duration of the excitement; and frequent attacks of mania almost invariably subside at last into imbecility.

401. In these cases of undue excitement, there is obviously an increase in the supply of blood to the head, as indicated by the suffusion of the face, the injection of the conjunctiva, the throbbing at the temples, the pulsation of the carotids; and we find that measures which diminish the activity of the circulation through the brain, are those most effectual in subduing the excitement. But it does not at all follow, that this undue action of the brain should be connected with an *excess* in the whole amount of nutritive material, and should require general depletion for its treatment. In fact, a very similar class of symptoms may present itself under two conditions of an entirely opposite kind,—*inflammation*, accompanied with an increase in the proportion of fibrin in the blood, and requiring treatment of a lowering kind,—and *irritation*, depending on a state of blood in which there is a deficiency of solid materials, and requiring a strengthening and even a stimulating regimen. The skill of the practitioner is often put to the test, in the due discrimination between these states.

402. The preceding examples mark the influence of various causes upon the actions of the vesicular matter of the *brain;* others might be adduced to show that the vesicular substance of the *spinal cord* is also liable to have its powers depressed or excited; but these will be best adverted-to hereafter, when the distinct functions of that organ are under consideration (CHAP. XII.). We may simply notice, that the stimulating effect of Strychnia is peculiarly and most remarkably exerted upon the vesicular substance of the spinal cord; and that a corresponding state, in which violent convulsive actions are excited by the most trifling causes, sometimes presents itself as a peculiar form of disease, named Tetanus, which may be either *idiopathic*, depending probably upon a disordered condition of the blood, or *traumatic*, consequent upon the irritation of a wound.

403. But, as formerly remarked, it is not in the Nervous *centres* only that changes originate. Whenever an impression is made upon the surface of the body, or upon the organs of special sense, which, being conducted to the nervous centres, either excites a sensation in the brain (§ 390), or a reflex action through the spinal cord (§ 392), the reception and propagation of such impression at the *extremities* of the sensory nerves, requires a set of conditions of

the same kind with those which we have seen to exist in the nervous centres. In fact, if we regard the course of the *motor* nerves as commencing in the nervous centres and terminating in the muscles, we may with equal justice consider that of the *sensory* nerves as originating in their peripheral extremities, and terminating in the sensorium. And, as already stated (§ 381), precisely the same kind of vesicular structure exists in some (probably in all) of the peripheral expansions of the sensory nerves, as makes-up the grey substance of the brain and spinal cord. Now it is easily shown, that the circulation of blood through these parts is just as necessary for the original reception of the impressions, as is the circulation through the brain to their reception as sensations and to the origination of motor impulses by an act of the will. We find that anything which retards the circulation through a part supplied by sensory nerves, diminishes its sensibility; and that if the flow of blood be completely stagnated, entire insensibility is the result. A familiar example of this is seen in the effects of prolonged cold; which, by diminishing, and then entirely checking, the flow of blood through the skin, produces first numbness and then complete insensibility of the part. This result, however, may be partly due to the direct influence of the cold upon the nerve-vesicles themselves; depressing their peculiar vital powers (§ 97). The same effect is produced, however, when the supply of blood is checked in any other way; as, for example, by pressure on the artery, or by obstruction in its interior. Thus when the main artery of a limb is tied, numbness of the extremities is immediately perceived; and this continues, until the circulation is re-established by the collateral branches, when the usual amount of sensibility is restored. Again, in the gangrene which depends upon obstruction of the arterial trunks by a fibrinous clot in their interior, diminution of sensibility, consequent upon the insufficient circulation, is one of the first symptoms.

404. On the other hand, increased circulation of blood through a part produces exaltation of its sensibility; that is, the ordinary impressions produce changes of unusual energy in its sensory nerves. This is particularly evident in the increased sensibility of the genital organs of animals during the period of heat; and in those of Man when in a state of venereal excitement. Moderate warmth, friction, exercise, and other causes which increase the circulation through a part, also augment its sensibility; and this augmentation is one of the most constant indications of that state of *determination of blood* or *active congestion*, which usually precedes inflammation, and which exists in the parts surrounding the centre of inflammatory action. But it must be borne in mind, here as elsewhere (§ 401), that such exaltation of function in a limited part is quite consistent with general debility; and in fact the tendency to such local affections is often particularly great, when the blood is in a very poor condition. (See CHAP. V.)

405. To sum-up, then, we may compare the vesicular substance, wherever it exists, to a galvanic combination: the former being capable of generating nervous influence, and transmitting it along the fibrous structure, to the part on which it is to operate; in the same manner as the latter generates electric power, and transmits it along the conducting wires, to the point at which it is to effect a decomposition or any other change. In one of the most perfect forms of the galvanic battery (that invented by Mr. Smee), although the metals remain immersed in the acid solution, and are consequently always ready for action, no electricity is generated unless the circuit be complete; and the *waste* of the zinc, produced by its solution in the acid, is therefore exactly proportional to the electric effects to which it gives-rise. The condition of the nervous system, in the healthy and waking state, bears a close analogy to this; for it is in a state constantly ready for action, but waits to be excited; and its waste is proportional to the activity of its function.—The vesicular matter, diffused over the surface of the body, is inactive, until an impression is made upon it by some external agent; but a change then takes-place in its condition (of which we know no more, than that the presence of arterial blood and a certain amount of warmth, are necessary for it), which is transmitted to the central organs by the sensory trunks. It would appear that the excitement of this change has a tendency to increase the afflux of blood to the part; thus when a lozenge or some similar substance is allowed to lie for a time in contact with the tongue, or with the side of the mouth, a roughness is produced, which is due to the erection of the sensory papillæ, by the distension of their blood-vessels.—On the other hand, the change in the vesicular matter of the central organs, by which motion is produced in the distant muscles, may be excited either by the stimulus conveyed by the afferent nerves (as in reflex action, § 392), or by an act of *Mind*. This act may be voluntary, originating in the will; or it may be instinctive or emotional, resulting from certain states of mind excited by sensations, and altogether independent of the will. Of the mode in which the mind thus acts upon the nervous system, we know nothing whatever, and probably never shall be informed in our present state of being. But it is sufficient for us to be aware of the physiological *fact* of the peculiar connection between the Mind and the Brain; a connection so intimate, as to enable the mind to receive through the body a knowledge of the condition of the universe around it, and to impress on the body the results of its own determinations; and of such a nature, that the regularity of the working of the mind itself is dependent upon the complete organization of the brain in the first instance, upon the constant supply of pure and well-elaborated blood, and upon all those influences which favour the due performance of the nutritive operations in general.

BOOK II.

SPECIAL PHYSIOLOGY.

CHAPTER IV.

OF FOOD, AND THE DIGESTIVE PROCESS.

1. *Sources of the Demand for Aliment.*

406. THE dependence of all Organized beings upon food or aliment, must be evident from the facts stated in the preceding portion of this Treatise. In the first place, the germ requires a large and constant supply of materials, with which it may develope itself into the perfect being, by the properties with which it is endowed. In all but the lower tribes of Plants, we find the materials required for the earliest stages of the process prepared and set-apart by the parent. Thus in the *seed*, the germ itself forms but a small proportion of the whole substance, the principal mass being composed of starchy matter, which is laid-up there for its nutrition; and the act of germination consists in the appropriation of that nutriment by the germ, and the consequent development of the latter, up to the point at which it becomes independent of such assistance, and is able to procure for itself, from the soil and atmosphere that surround it, the materials for its continued growth. So in the *egg* of the Animal, the principal mass is composed of Albumen and oily matter; the germ itself being, at the time the egg is first deposited, a mere point invisible to the naked eye; these materials serve as the food or aliment of the germ, which gradually draws them to itself, and converts them into the materials of its own structure; and at the end of a certain period, the young animal comes-forth from the egg, ready to obtain for itself the food which is necessary for its continued increase in size.

407. In many instances among the lower tribes, the form in which the young animal emerges from the egg is very different from that which it is subsequently to assume; and the latter is only attained by a process of *metamorphosis*. This change has been longest known and most fully studied in the case of Insects and Frogs, which were formerly thought to constitute an exception to all general rules in this respect,—the Insect coming-forth from the egg in the state of a Worm, and the Frog in the condition of a

Fish. But it is now known that changes of form, as complete as these, occur in a large proportion of the lower tribes of Animals; so that the *absence* of them is the exception. The fact seems to be, that the supply of nutriment laid-up within the egg, among the lower classes, is by no means sufficient to carry-on the embryo to the form it is subsequently to attain; and its development is so arranged, that it may come into the world in a condition which adapts it to obtain its own nutriment, and thus to acquire for itself the materials for its further development. Thus the Insect, in its *larva* or Caterpillar state, is essentially a fœtus in regard to its grade of development; but it is a fœtus capable of acquiring its own food. In this condition it attains its full growth as regards *size*, though its *form* remains the same; but it then, in passing into the Chrysalis state, reassumes (as it were) the condition of an embryo within the egg,—the development of various new parts takes-place, at the expense of the nutriment stored-up in its tissues, —and it comes-forth as the perfect Insect. In many of the lower tribes, the animal quits the egg at a still earlier period in comparison; thus it has been shown by Prof. Milne-Edwards, that some of the long marine worms consist only of a single segment, forming a kind of head, when they leave the egg; and that the other segments, to the number (it may be) of several hundred, are gradually developed from this, by a process that resembles the budding of Plants.

408. Up to the period, then, when the full dimensions of the body have been attained, and the complete evolution of all its organs has taken-place, a due supply of food is necessary for these purposes. In the Plant, nearly the whole of the alimentary materials taken into the system are thus appropriated; the extension of its structure going-on almost indefinitely, and the waste occasioned by decay being comparatively small. Thus the carbon, which is given out by the respiratory process in the form of carbonic acid, bears but a small proportion to that which is introduced by the decomposition of that same gas under the influence of light (§ 81). And the fall of the leaves, which takes-place once a year or more frequently, and which gives-back a large quantity of the matter that has undergone the organizing process, does not occur, until by their means a considerable addition has been made to the solid and permanent substance of the tree.

409. This is not the case, however, with the Animal. Its period of *increase* is limited. The full size of the body is usually attained, and all the organs acquire their complete evolution, at a comparatively early period. The continued supply of food is not then requisite for the extension of the structure, but simply for its maintenance; and the source of the demand lies in the constant *waste*, to which, during its period of activity, it is subjected. We have seen that every action of the Nervous and Muscular systems

involves the death and decay of a certain amount of the living tissue,—as is indicated by the appearance of the products of that decay in the Excretions; and a large part of the demand for food will be consequently occasioned by the necessity for making-good the loss thus sustained. Hence we find that the demand for food bears a close relation to the activity of the animal functions; so that a diet which would be superfluous and injurious to an individual of inert habits, is suitable and beneficial to one who is leading a life of continual exertion; and this difference manifests itself in the requirements of the same individual who makes a change in his habits,—the indolent man acquiring an appetite by vigorous exertion, and the active man losing his disposition to hearty feeding by any cause that keeps him from his accustomed exercise. We see precisely the same contrast between Animals of different tribes, whose natural instincts lead them to different modes of life. The Birds of most active flight, and the Mammals which are required to put-forth the greatest efforts to obtain their food, need the largest and most constant supplies of nutriment; but even the least active of these classes stand in remarkable contrast with the inert Reptiles, whose slow and feeble movements are attended with so little waste, that they can sustain life for weeks and even months, with little or no diminution of their usual activity, without a fresh supply of food.

410. The waste and decay just adverted-to, however, do not affect the muscular and nervous tissues alone; for all the operations of nutrition involve it to a certain extent. It has been already shown that the acts of absorption, assimilation, respiration, secretion, and reproduction,—all those, in fact, by which the material for the nutrition of the nervous and muscular tissues is first prepared, and subsequently maintained in the requisite purity,—are effected in the Animal, as in the Plant, by the agency of cells, which are continually dying and requiring renewal. In most Vegetables, the death of the parts concerned in these functions takes-place simultaneously, as soon as they have performed them; the whole crop of leaves ceasing at once to perform its proper actions, and dropping off;—to be replaced by another, at an interval that solely depends upon the temperature under which the tree is living (§ 99). In the evergreen, however, the process bears a close resemblance to that which we observe in the Animal; for the leaves die one by one, not simultaneously, and are constantly undergoing replacement; so that the vigour of the system, and the activity of its nutritive processes, never suffer a complete suspension.

411. In the Animal body, the different classes of cells to which allusion has been made, are in like manner constantly undergoing death and renewal; and this with a rapidity proportioned to the energy of their functions. Hence a supply of food is as requisite to furnish the materials of their growth, as it is in Plants to furnish

the materials of the growth of their leaves. A large part of these materials are subsequently used for other purposes in the economy; thus, as the leaves prepare the sap which is to nourish the woody stem, and to form new shoots, so do the absorbing and assimilating cells prepare and furnish the fluid elements of the blood, which are to repair the waste of nerve and muscle, bone and cartilage, &c. But still a considerable amount is expended in the simple nutrition of these organs themselves, whose duration is transient, and whose solid parts are cast-off as of no further use. Thus the skin and all the mucous surfaces are continually forming and throwing-off epidermic and epithelial cells, whose formation requires a regular supply of nutriment; and only a part of this nutriment (that which occupies the *cavity* of the cells) consists of matter that is destined to serve some other purpose in the system, or that has already answered it; the remainder (that of which the solid walls are composed) being furnished by the nutritive materials of the blood, and being henceforth altogether lost to it.—Thus every act of Nutrition involves a waste or decay of Organized tissue.

412. We may observe a marked difference, however, between the amount of aliment required, and the amount of waste occasioned, by the simple exercise of the *nutritive* or *vegetative* functions in the building-up and maintenance of the animal body, and that which results from the exercise of the *animal* functions. The former are carried-on, with scarcely any intermixture of the latter, during fœtal life. The aliment, in a state of preparation, is introduced into the fœtal vessels; and is conveyed by them into the various parts of the structure which is developed at its expense. The amount of *waste* is then very trifling, as we may judge by the small amount of excretory matter, the product of the action of the liver and kidneys, which has accumulated at the time of birth; although these organs have attained a sufficient development to act with energy when called-upon to do so. But as soon as the *movements* of the body begin to take-place with activity, the waste increases greatly; and we even observe this immediately after birth, when a large part of the time is still passed in sleep, but when the actions of respiration involve a constant employment of muscular power.—In the state of profound *sleep*, at subsequent periods of life, the vegetative functions are performed, with no other exercise of the animal powers than is requisite to sustain them; and we observe that the waste, and the demand for food, are then diminished to a very low point. This is well seen in many animals, which lead a life of great activity during the warmer parts of the year, but which pass the winter in a state of profound sleep, without, however, any considerable reduction of temperature; the demand for food, instead of being frequent, is only felt at long intervals, and the excretions are much reduced in amount. And those animals which become completely inert, either by the influence of cold, or by the drying-up

of their tissues, do not suffer from the prolonged deprivation of food; because not only are their animal functions suspended, but their nutritive operations also are in complete abeyance; and the continual decomposition of their tissues which would otherwise be taking-place, is checked by the cold or desiccation; so that the whole series of changes which goes-on in their active condition, is completely at a stand.

413. But there is another most important cause of demand for food, amongst the higher Animals, which does not exist either amongst the lower Animals, or in the Vegetable kingdom. We have seen (CHAP. II.) that Mammals and Birds, and to a certain extent Insects also, are able to sustain the heat of their bodies at a fixed standard, and thus to become independent of variations in external temperature. This they are enabled to do, as will be explained hereafter, by a process strictly analogous to ordinary combustion; the carbon and hydrogen which are directly supplied by their food, or which have been employed for a time in the composition of the living tissues and are then set-free, being made to unite with oxygen introduced by the respiratory process, and thus giving-off as much heat as if the same materials were burned in a furnace. And it has been further shown, that the immediate cause of death in a warm-blooded animal from which food has been entirely withheld, is the inability any longer to sustain the temperature which is requisite for the performance of its vital operations (§ 117). Hence we see the necessity for a constant supply of aliment, in the case of warm-blooded animals, for this purpose alone; and the demand will be chiefly regulated by the external temperature. When the heat is rapidly carried-off from the surface, by the chilling influence of the surrounding air, a much greater amount of carbon and hydrogen must be consumed within the body, to maintain its proper heat, than when the air is nearly as warm as the body itself; so that a diet which is appropriate to the former circumstances, is superfluous and injurious in the latter; and the food which is amply sufficient in a warm climate, is utterly destitute of power to enable the body to resist the influence of severe cold. This is a fact continually experienced, both in the ordinary recurrence of changes of temperature in our own climate, and still more remarkably, when the same individual is subjected to the extremes of heat and cold, in successively visiting the tropical and frigid zones.

414. Thus we find that in the Animal body, aliment is ordinarily required for four different purposes. *First*, for the original construction or building-up of the organism. *Second*, to supply the loss occasioned by the vital actions it is continually performing, even when in a state of repose. *Third*, to compensate for the waste occasioned by the active exercise of the nervous and muscular systems. And *Fourth*, to supply the materials for the heat-

producing process, by which the temperature of the body is kept up.—The amount required for these several purposes will vary according to the conditions of the body, as regards exercise or repose, and external heat or cold. It is also subject to great variation with difference of *age*. During the period of growth, it might be anticipated that a larger supply of food would be required, than when the full stature has been attained; but a very small daily addition would suffice in the case of a child or youth, to produce the entire increase of a whole year. Yet every one knows that the child requires *much* more food than the adult, in proportion to his comparative bulk. This results from the much more rapid *change* in the constituents of his fabric; which is evident from the large proportional amount of his excretions, from the quickness with which the effects of illness or of deficiency of food manifest themselves in the diminution of the bulk and firmness of the body, from the short duration of life when food is altogether withheld, and from the readiness with which losses of substance by disease or injury are repaired, when the nutritive processes are restored to their full activity. The converse of all this holds good in the aged person. The excretions diminish in amount, the want of food may be sustained for a longer period, losses of substance are but slowly repaired, and everything indicates that the interstitial changes are performed with comparative slowness; and, accordingly, the demand for food is far less in proportion to the bulk of the body than it is in the adult, and may be even absolutely less than in the child of a fourth of its weight.

415. The demand for food is increased by any cause, which creates an unusual *drain* or *waste* in the system. Thus an extensive suppurating action can be sustained only by a large supply of highly nutritious food. The mother, who has to furnish the daily supply of milk which constitutes the sole support of her offspring, needs an unusual sustenance for this purpose. And there are states of the system, in which the solid tissues seem to possess an unusual tendency to decomposition, and in which an increased supply of aliment is therefore required. This is the case, for example, in diabetes; one of the first symptoms of which disease is the craving appetite, that seems as if it would never be satisfied. And there can be no doubt that, putting aside all the other circumstances that have been alluded-to, there is much difference amongst individuals, in regard to the rapidity of the changes which their organism undergoes, and the amount of food required for its maintenance.

416. The influence of the supply of food upon the size of the individual, is very evident in the Vegetable kingdom; and it is most strikingly manifested, when a plant naturally growing in a poor dry soil is transferred to a damp rich one, or when we contrast two or more individuals of the same species, growing in localities of opposite characters. Thus, says Mr. Ward, "I have gathered, on the cha-

borders of a wood in Kent, perfect specimens in full flower of *Erythræa Centaurium* (Common Centaury), not more than half an inch in height; consisting of one or two pairs of most minute leaves, with one solitary flower: these were growing on the bare chalk. By tracing the plant towards and in the wood, I found it gradually increasing in size, until its full development was attained in the open parts of the wood, where it became a glorious plant, four or five feet in elevation, and covered with hundreds of flowers." On the other hand, by starvation naturally or artificially induced, Plants may be dwarfed or reduced in stature: thus the Dahlia has been diminished from six feet to two; the Spruce Fir from a lofty tree to a pigmy bush; and many of the trees of plains become more and more dwarfish as they ascend mountains, till at length they exist as mere underwood. Part of this effect, however, is doubtless to be attributed to diminished temperature; which, as already remarked, concurs with deficiency of food in producing inferiority of size.

417. Variations in the supply of food would not appear to be effectual in producing a corresponding variety of size in the Animal kingdom: this is not, however, because Animals are in any degree less dependent than Plants upon a due supply of food; but because such a limitation of the supply as would *dwarf* a Plant to any considerable extent, would be fatal to the life of an Animal. On the other hand, an excess of food, which (under favourable circumstances) would produce great increase in the size of the Plant, would have no corresponding influence on the Animal; for its size appears to be restrained within much narrower limits,—its period of growth being restricted to the early part of its life, and the dimensions proper to the species being rarely exceeded in any great degree. Even in the case of *giant* individuals, it does not appear that the excess of size is produced by an over-supply of food; but that the larger supply of food taken-in is called-for by the unusual wants of the system,—those wants being the result of an extraordinary activity in the processes of growth, and being traceable rather to the properties inherent in the system, than to any external agencies. Thus we not unfrequently hear of children, who have attained an extraordinary size at the age of a few years; and this excess of size is usually accompanied with other marks of precocious development. We shall hereafter see that a provision exists in the Digestive apparatus, which absolutely prevents the reduction and preparation of the food, in any amount greatly surpassing that which the wants of the system demand (§ 474); and it is probably to this cause, in part, that we are to attribute the small degree of influence exerted by an excess of food, in producing an increased development of the Animal frame.

418. The influence of a diminished supply of food, in producing a marked inferiority in the size of Animals, is most effectually

exerted during those early periods of growth, in which the condition of the system is most purely Vegetative. Thus it is well known to Entomologists, that, whilst it is rare to find Insects departing widely from the average size on the side of excess, dwarf-individuals, possessing only half the usual dimensions, or even less, are not uncommon; and there can be little doubt that these have suffered from a diminished supply of nutriment during their larva state. This variation is most apt to present itself in the very large species of Beetles, which pass several years in the larva state; and such dwarf specimens have even been ranked as sub-species. Abstinence has been observed to produce the effect, upon some Caterpillars, of diminishing the number of moults and accelerating the transformation; in such cases, the Chrysalis is more delicate, and the size of the perfect Insect much below the average.

419. One of the most remarkable examples known, of the effect of food in modifying the development of Animals, is to be found in the economy of the Hive-Bee. In every community, the majority of individuals consists of *neuters;* which may be regarded as females, having the organs of the female sex undeveloped; and which, whilst incapable of reproduction, perform all the labours of the hive. The office of continuing the race is restricted to the *queen;* who is the only perfect female in the community. If by any accident the queen be destroyed, or if she be purposely removed for the sake of experiment, the bees choose two or three from amongst the *neuter larvæ*, which are being nurtured in their appropriate cells; and these they cause to be developed into *perfect queens*. The first operation is to change the cells in which they lie, into *royal cells;* these differ considerably from the ordinary ones in form, and are of much larger dimensions. This is accomplished by breaking-down the walls of the surrounding cells, removing the eggs or grubs they may contain, and rebuilding the central cell upon an enlarged scale, and upon the same plan as the royal cells in which the queens are ordinarily reared. Whilst this operation is going-on, the maggot is supplied with food of a very different nature from the farina or bee-bread (composed of a mixture of pollen and honey) which has been stored-up for the nourishment of the workers; this food being of a jelly-like consistence and pungent stimulating character. After the usual transformations, the grub becomes a perfect queen; differing from the neuter-bee, into which it would have otherwise been changed, not only in the development of the reproductive system, but in the general form of the body, the proportionate shortness of the wings, the shape of the tongue, jaws, and sting, the absence of the hollows on the thighs in which the pollen is carried, and the loss of the power of secreting wax.

420. That insufficiency of wholesome food, continued through successive generations, may produce a marked effect, not merely upon the stature, but upon the form and condition of the body,

even in the Human race, appears from many cases in which such influence has operated on an extensive scale. Thus there are parts of Ireland inhabited by a population descended from those who were treated by the English as rebels two centuries since, and who were driven into mountainous tracts, bordering the sea, where they have been since exposed to the two great brutalizers of the human race, hunger and ignorance. The present race is distinguished physically from the kindred race of Meath and other neighbouring districts, where the same causes have not been in operation, by their low stature (not exceeding five feet two inches), their pot-bellies and bow-legs; whilst their open projecting mouths, with prominent teeth and exposed gums, their advancing cheek-bones and depressed noses, bear barbarism in their very front. "These spectres of a people that once were well-grown, able-bodied, and comely, stalk abroad into the daylight of civilization, the annual apparitions of Irish ugliness and Irish want."—The aboriginal population of New Holland, as a whole, presents a similar aspect; and apparently from the operation of the same causes.

421. When a larger quantity of azotized food (§ 429) is habitually consumed than the wants of the system require, it is not converted into solid flesh; but it is got-rid-of by the various processes of excretion. The increased production of Muscular fibre depends, as we have already seen (§ 362), upon nothing so much as the exercise of the muscle. It cannot take-place, unless the blood supply it with the materials: but no degree of richness of the blood can alone produce it. Consequently, the accumulation of nutritive matter in the blood is so far from being a condition of *health*, that it powerfully tends to produce *disease*,—either of an inflammatory character, if the fibrin predominate,—or of the hemorrhagic character, if the red corpuscles predominate. This state is most apt to present itself in those who live well and take little exercise; and the remedy for it is either to diminish the diet, or to increase the amount of exercise, so as to bring the two into harmony.

422. The continued over-supply of food has several injurious effects: it disorders the digestive processes, by stimulating them to undue activity, and lays the foundation for a complete derangement of them; it gives a predisposition to the various diseases of repletion, as just noticed; and it throws upon the excreting organs much more than their proper amount of labour, besides tending to produce a depraved condition of the matters to be drawn-off by them, which renders the proper act of excretion still more difficult. When this is the case, various disorders arise, caused by the retention, within the circulating current, of substances which are very noxious to the general system, and which become most fertile sources of disease. What are commonly regarded as diseases of the biliary and urinary organs, are really, in a large proportion of cases, nothing else than disordered actions of those organs,

occasioned by the irregular mode in which the products of decomposition are formed within the blood, and dependent upon some error in diet, either as regards quantity or quality. Thus the "lithic acid diathesis," in which there is an undue proportion of that substance in the urine, and of which Gout is a particular manifestation, is due, not to disorder of the kidney, but to an undue production of lithic acid in the blood. So long as the excreting action of the kidney is sufficient to prevent its accumulation in the blood, so long the general health is but little affected; but whenever that action receives a check, various constitutional symptoms indicate that the system is disturbed by the presence of this product of decomposition. And though our remedies may be rightly directed in part to facilitating its escape through the kidneys, yet the radical cure is to be sought only in the regulation of the diet, and in the prevention of the first production of the substance in question.—Similar remarks might probably be applied to disorders of the Liver; but we are, from various causes, far less perfectly acquainted with their character, than we are with those of the Kidney.

423. There is only one tissue, the increase of which is directly produced by an over-supply of food. This is the Adipose or fatty. It is formed almost entirely at the expense of the non-azotized constituents of the food (§ 430); the walls of the cells within which the fatty matter is secreted (§ 257), being the only part of this tissue that is derived from the protein-compounds of the blood. The production of the adipose tissue is most directly favoured by the presence of a large amount of fatty matter in the food; but it may also be effected, as will be presently shown, by the conversion of starchy and saccharine substances into fatty compounds. It cannot occur, unless there be in the food a larger proportion of substances that can be thus appropriated, than is sufficient to maintain the heat of the system by the respiratory process. Consequently, whatever increases the demand for heat, is unfavourable to the deposition of fat; and *vice versâ*. The fattening of animals is now brought to a regular system; and experience has shown that rest and a warm temperature, with food containing a large amount of oily matter, are most conducive to the accumulation. Rest acts by keeping the respiration at a low standard; for it will hereafter be shown (§§ 645, 692), that a much larger proportion of carbonic acid is thrown-off when the body is in active movement, than when it is in repose. External warmth has the same effect; the demand upon the calorifying power being diminished, and more of the combustible material being left, to be stored-up as fat.

424. The deposition of fat affords a supply of combustible matter against the time when it may be needed; and it is consequently found that the duration of life in warm-blooded animals, when they are completely deprived of food, is in great degree proportional

to the amount of fat they have previously accumulated. There is no reason whatever to believe, that fatty matter can be converted within the animal body into a protein-compound, fitted to serve for the nutrition of the muscular and other tissues. But the greatest and most constant waste, when an animal is undergoing starvation, is that which is occasioned by the heat-producing process; this, so long as the supply lasts, is kept-up by the store of fat, which is gradually consumed; and when it is completely exhausted, the temperature falls, hour by hour, until life can no longer be sustained (§ 117). The use of this store of fat, in supplying any temporary deficiency in the food, becomes evident from such experiments; for when it has been completely exhausted, the withholding of a single meal proves fatal, from the want of power to sustain the calorifying process. We find that animals which are likely to suffer from deficiency of food in the winter, or which spend that period in a state of quiescence, have a tendency to accumulate a store of fat in the autumn; which tendency seems principally to depend upon the nature of their food. We observe it chiefly in those Birds and Mammals which live upon seeds and grains; and these, when ripe, contain a large quantity of oily matter, which thus becomes a valuable store against the time of need. There are many birds, such as the beccafico so much esteemed in Italy, which are described, if killed at this season, as being "lumps of fat."

425. It is well known to breeders of cattle, that some varieties or breeds have a much greater tendency to the production of Adipose tissue, than others placed under the same circumstances; and the former are therefore selected to undergo the fattening process. Corresponding differences may be met-with among different individuals of the Human race; some persons having a remarkable tendency to the production of fat, under circumstances which do not seem by any means favourable to it, whilst others appear as much indisposed to this deposit. The latter condition we notice particularly in that temperament which is commonly termed the 'bilious;' and it is important to bear in mind that, where such an indisposition exists, any superfluity of fatty matter in the food taken into the system, must be excreted again through the liver, instead of being retained and stored-up in the body. It is very desirable, therefore, that such persons should abstain from any excess of this kind; since an habitual call upon the liver to relieve the system of a superfluity of fatty matter, is certain to produce a disordered state of that organ; and in order to prevent it, the diet should be altered, so as to include less of fatty matter, or the amount of exercise should be increased, so that it may be burned-off by the additional respiration which then takes-place.

426. We see, then, that the amount of food which can be properly appropriated by the system, varies considerably in different indi-

viduals, and in the same individual under different circumstances. Consequently it is impossible to give any general rule, which shall apply to every one alike. The *average* quantity required by adult men, leading an active life, and exposed to the ordinary vicissitudes of temperature in our own climate, seems to be from 30 to 36 ounces of *dry* aliment. But if the muscular powers are but little exerted, and the surrounding temperature be high, a healthy condition may be kept-up on scarcely more than half this allowance; provided that it consists of substances of a nutritious kind, united in proper proportions.

427. The value of different substances as aliment, depends in the first place upon the quantity of solid matter they contain; being of course the greater, as the solids form the larger proportion of the entire weight. Many esculent vegetables contain so large a quantity of water, that the nutriment they afford is very slight in proportion to their bulk; and even in animal flesh, only about one-fourth consists of solid matter; the remainder being water.—Next it depends upon the proportion of digestible matter which the solid parts include; for it is not every substance containing the requisite ingredients, that is capable of being reduced to a state which enables it to be absorbed. Thus woody fibre has the same elementary composition as starch-gum; but it passes-out of the intestinal canal unchanged, and therefore affords no nutriment. In the same manner, the horny tissues of animals, though nearly allied to albumen in their composition, are completely destitute of nutritive properties to Man and the higher animals, because not capable of being reduced by their digestive process; though certain insects appear capable of living exclusively upon them.

428. But when the watery and indigestible parts of the food are put out of consideration, and our attention is directed only to the soluble solids, we find a most important difference in the chemical composition of different substances, which renders them more or less appropriate to the different purposes which have to be answered in the nutrition of the body. It has been already pointed-out, that Vegetables possess the power of combining the *elements* furnished by the inorganic world into two classes of compounds,—the ternary, consisting of oxygen, hydrogen, and carbon,—and the quaternary, which consists of these elements with the addition of azote or nitrogen. These two classes are hence termed the *non-azotized*, and the *azotized*.

429. Now the Azotized compounds are required for the reparation of the waste of the nervous and muscular tissues, and for the general nutrition of the body; consequently, unless the food contain a sufficient proportion of these substances, the body must be insufficiently nourished and the strength must diminish, even though other elements of the food be in superabundance. The azotized substances formed by Plants are essentially the same, as already shown

(§ 174), with those which are furnished by the Albuminous solids and fluids of Animals; but the quantity of them is usually small in proportion to the non-azotized, being considerable only in the Corn-grains, in the seeds of Leguminous plants, and in some other products, which the universal experience of ages has demonstrated to be the most nutritious of Vegetable substances. The other azotized compounds existing in the animal body, may be elaborated by the transformation of these albuminoid compounds; so that when *they* are duly supplied, the system cannot become enfeebled for want of support.—But there is another azotized compound, Gelatin, that is furnished by Animals, to which nothing analogous exists in Plants; and this is commonly reputed to possess highly nutritious properties. It may be confidently affirmed, however, as the result of experiments made upon a large scale, that Gelatin is incapable of being converted into Albumen in the animal body, so that it cannot be applied to the nutrition of the albuminous tissues. And although it might *a priori* be thought not unlikely, that Gelatin taken-in as food should be applied to the nutrition of the gelatinous tissues (§ 185), yet neither observation nor experiment bears-out such a probability. For, on the one hand, the study of the development of these tissues leads to the conclusion, that they have their origin, like those whose constitution is albuminous, in the plasma of the blood, which does not contain gelatin; whilst, on the other, the introduction of gelatin into the blood is speedily followed by such a large increase in the excretion of urea, as renders it almost certain that this substance must have undergone decomposition in the system, so as to be removed from it by the action of the lungs and kidneys. Consequently, the use of gelatin as food would seem to be limited to its power of furnishing a certain amount of combustive material which may assist in maintaining the heat of the body; and there is this advantage in combining a proportion of gelatin with the diet,—especially when the digestive powers are feeble,—that being already in a state of perfect solution, it is taken-up at once by the simple act of physical absorption or endosmose, instead of requiring any preliminary preparation or an exertion of vital activity for its absorption.

430. The Non-azotized compounds, which are presented to us in great abundance in the Vegetable kingdom, exist under various forms; of which the principal are starch, sugar, and oil. The two former may be regarded as belonging to one class, the Saccharine; because we know that starch and the substances allied to it may be converted into sugar by simple chemical processes, and that this transformation takes-place readily both in the Vegetable and Animal economy. On the other hand, the Oily matters contained in vegetable and animal food, are usually ranked as a distinct group of alimentary substances; and it has been maintained that, under no circumstances, has the Animal the power of elaborating fatty matter

from starchy or saccharine compounds. But this is now known to be an unfounded limitation; since the transformation of a saccharine into a fatty compound takes-place in the case of bees, which form wax when fed upon pure sugar; and it has been further shown that it may take-place in the laboratory of the Chemist, butyric acid (the fatty acid of butter) being one of the products of the fermentation of sugar occurring under peculiar circumstances.

431. The great use of these substances in the Animal economy, is to support the Respiratory process, and thus maintain the temperature of the body. We have seen that, in the compounds of the *Saccharine* group (in which Starch is included) the amount of oxygen is no more than sufficient to form water with the hydrogen of the substance (§ 12); so that the carbon is free to combine with the oxygen taken-in by the lungs, and thus becomes a source of calorifying power. Again, in the oily matters taken-in as food, the proportion of oxygen is far smaller, so that they contain a large quantity of surplus hydrogen, as well as of carbon, ready to be burned-off in the system, and thus to supply the heat required. This is obviously the ordinary destination of the alimentary matters belonging to these classes; and the greatest economy in the choice of diet is therefore exercised, when it is composed of azotized substances in sufficient amount to repair the waste of the system, and of non-azotized compounds which include free carbon and hydrogen in sufficient quantity to develope (with the aid of other processes) the requisite amount of heat by combination with oxygen. But if there be a deficiency in either of these kinds of aliment, the body must suffer. Should the supply of duly-prepared azotized matter be less than is required to repair the waste of the albuminous and gelatinous tissues, then these diminish in bulk and in vital power, though the heat of the body may be kept-up to its proper standard. But if the non-azotized matter should be supplied in insufficient amount, or in a form in which it cannot be appropriated, the heat of the body cannot be sustained in any other way than by drawing upon the store of fat previously laid-up.

432. Various circumstances lead to the belief, that the saccharine compounds are thus carried-off by the respiratory process, within a short time after they have been introduced into the system. They have not been detected in the chyle drawn from the lacteal absorbents; but there seems reason to believe that, in consequence of their ready solubility, they are directly taken-up by the blood (§ 493), and that they are so rapidly burned-off there, as to escape notice in that fluid. But it has been shown by Prof. Buchanan, that, if the blood be examined within a short time after a meal consisting in part of farinaceous and saccharine substances, a very appreciable quantity of saccharine matter is found in it. This soon disappears, however; being eliminated or separated from the blood by the action of the lungs. In fact it is very probable, that a large

proportion of the matter thus taken-in never enters the general circulation at all; since the blood of the mesenteric veins proceeds to the lungs, after passing through the liver, before it is transmitted to the systemic arteries, and may there lose its saccharine matter, as fast as this is taken-in from the stomach. After a meal containing the ordinary admixture of saccharine, oily, and albuminous compounds, it is probable that the saccharine are first received into the blood, and are the first to be eliminated from it; and that, by the time *they* have been all consumed, the oily matter, introduced through the more circuitous channel of the lacteal system, is ready to answer the same purpose. If these combustive materials be exhausted before a fresh supply of food is taken-in, cold as well as hunger is experienced; and the body is in this condition peculiarly liable to suffer from any depressing causes, such as a low external temperature, poisonous miasmata, &c.; hence the prudence of avoiding exposure to such influences upon an empty stomach.

433. We can thus in part account for the fact, which universal experience has established, that in warm-blooded animals, a mixture of azotized and non-azotized substances is the diet most conducive to the welfare of the body; and that, in all but the purely carnivorous tribes, the diet provided by Nature consists not only of albuminous, gelatinous, and oily substances, such as are furnished by the flesh and fat of animals, but also of saccharine or farinaceous matter. This is the diet to which Man is evidently best adapted; and it is remarkable how completely accordant is his use of the ordinary materials of food, with the principles now established by chemical and physiological research, in regard to the wants of his bodily system, and the best mode of supplying them. Thus, good wheaten bread contains, more nearly than any other substance in ordinary use, that proportion of azotized and non-azotized matter, which is adapted to repair the waste of the system, and to supply the necessary amount of combustive material, under the ordinary conditions of civilized life in temperate climates; and we find that health and strength can be more perfectly sustained upon that substance, than upon any other taken alone. The addition of a moderate quantity of butter increases its heat-producing power; and this is especially useful when the temperature is low, under which condition there is usually an increased disposition to the employment of fatty matters as articles of food. The replacement of wheat by maize, which contains a considerable per-centage of oil, has been found to answer the same purpose. On the other hand, if the body be subject to violent exertion, it is found to be advantageous to increase the proportion of the protein-compounds, by the addition of animal flesh; the use of this, however, as a principal article of diet, except when the individual is leading the incessantly-active life of a carnivorous animal, is very far from being economical, and is positively injurious to the welfare of the body.

434. On the other hand, in rice, potatoes, cassava-meal, and similar substances, the farinaceous or saccharine components form so very large a proportion of the whole mass, and the protein-compounds are present in so very small an amount, that they are insufficient to support the bodily vigour when taken alone, unless a larger quantity be ingested, so as to supply the requisite proportion of azotized matter. But when these substances form part of a mixed diet, the other ingredients of which consists of animal flesh, a much smaller quantity of them suffices; and the same kind of combination is then formed, as exists in the single article of bread. Those in whose diet the farinaceous elements predominate largely, and the azotized compounds exist in the smallest amount compatible with the maintenance of the bodily vigour, are exempt from many diseases incident to those who live more highly; thus among the potato-eating Irish and the oatmeal-feeding Scotch, gout is a disease never heard of; whilst among the richer classes of the same countries, there is no peculiar exemption from it.

435. The oily constituents of food are most abundant in the diet of the inhabitants of frigid zones, who feed upon whales, seals, and other animals loaded with fat, and who devour this fat with avidity, as if instinctively guided to its use. It is by the enormous quantity of this substance taken-in by them, that they are enabled to pass a large part of the year in a temperature below that of our coldest winter, spending a great portion of their time in the open air; as well as to sustain the extreme of cold, to which they are occasionally subjected. And in consequence of its being more slowly introduced into the system than most other substances, a larger quantity may be ingested at one time, without palling the appetite; whilst its bland and non-irritating character favours its being retained until it is all absorbed. In this manner the Esquimaux and Greenlanders are enabled to take-in 20 or 30 pounds of blubber at a meal; and, when thus supplied, to pass several days without food.—On the other hand, among the inhabitants of warm climates there is comparatively little disposition to the use of oily matter as food; and the quantity of it contained in most articles of their diet is comparatively small.

436. In the Milk, which is the sole nutriment of young Mammalia during the period immediately succeeding their birth, we find an admixture of albuminous, saccharine, and oleaginous substances; which indicates the intention of the Creator, that all these should be employed as components of the ordinary diet. The Caseine or cheesy matter is a protein-compound; the Butyrine of butter is but a slight modification of the ordinary fats; and its Sugar differs from that in common use, only by its larger proportion of water. The relative amount of these ingredients in the milk of different animals is subject, as we shall hereafter see, to considerable variation; but they constantly exist, at least in the milk of the Herbivorous

Mammalia, and of those which, like Man, subsist upon a mixed diet. The milk of purely Carnivorous animals, however, contains scarcely any Sugar, so long as they are fed upon a purely animal diet; chiefly consisting, like their food, of protein-compounds and fatty matter.

437. No fact in Dietetics is better established, than the impossibility of long sustaining health, or even life, upon any single alimentary principle. Neither pure albumen or fibrin, gelatin or gum, sugar or starch, oil or fat, taken alone for any length of time, can serve for the due nutrition of the body. This is partly due, so far as the non-azotized and gelatinous compounds are concerned, to their incapability of supplying the waste of the albuminous tissues. This reason does not apply, however, to the protein-compounds; which can not only serve for the reparation of the body, but can also afford the carbon and hydrogen requisite for the sustenance of its temperature. The real cause is to be found in the fact, that the continued use of *single* alimentary substances excites such a feeling of disgust, that the animals experimented-on seem at last to prefer starvation rather than the ingestion of them. Consequently it is quite impossible to ascertain, by such experiments, the nutritive power of the different alimentary principles; no animal being capable of sustaining life upon less than two of them at least. The same disgust is experienced by Man, when too long confined to any article of diet which is very simple in its composition; and a craving for change is then experienced, which the strongest will is scarcely able to resist. Thus, in the treatment of Diabetes, a disease in which there is an undue tendency to the production of sugar in the system, it is very important to abstain completely from the introduction of saccharine or farinaceous matters in the food; but the craving for vegetable food, which is experienced when the diet has long consisted of meat alone, is such as to make perseverance in the latter very difficult; and a means has been devised of supplying this want without injury, by the use of bread from which the starchy portion has been removed, the gluten or azotized matter alone being eaten.*

438. The organic compounds which have been enumerated as supplying the various wants of the system, would be totally useless

* As an illustration of the advantage of this treatment, even in unpromising cases, the Author may cite an instance which came under his own observation. The patient was a man of 72 years of age; the disease had lasted at least a year, and was decidedly on the increase; considerable loss of flesh and of muscular vigour had taken place; and the quantity of sugar in the urine was such as to make it quite sweet to the taste. By the careful restriction of his diet to animal flesh and gluten-bread, this individual kept the disease in complete check for more than *five years;* he gained flesh and improved in strength; and his urine lost its sweetness. Having two or three times ventured upon a return to his ordinary diet, his old symptoms immediately manifested themselves, warning him of the necessity of perseverance in the strict regimen prescribed for him. He died at last, at the age of 77 years, of old age, rather than of any specific disease.

without the admixture of certain inorganic substances, which also form a constituent part of the bodily frame, and which are constantly being voided by the excretions, especially in the Urine. These substances have various uses in the system. Thus common *Salt*, or the Chloride of Sodium, appears to afford, by its decomposition, the muriatic acid which is concerned in the digestive process, and the soda which is an important constituent of the bile. Its presence in the serum of the blood, also, and in the various animal fluids which are derived from this, probably aids in preventing the decomposition of the organic constituents of these fluids,—*Phosphorus* was formerly supposed to be chiefly requisite as one of the materials of the nervous tissue (§ 383); and also, when acidified by oxygen, to unite with lime in forming the bone-earth by which bone is consolidated. But there is reason to believe that the acid and alkaline phosphate of lime and soda are very important constituents of the various fluid secretions, and have a large share in their respective actions.—*Sulphur* exists in small quantities in several animal tissues; but its part appears to be by no means so important as that performed by Phosphorus.—*Lime* is required for the consolidation of the bones, and for the production of the shells and other hard parts that form the skeletons of the Invertebrata; and also as the base of the acid phosphate, which has been just referred-to as an important constituent of the animal fluids.—Lastly, *Iron* is an essential constituent of Hæmatosine; and is consequently required for the production of the red corpuscles of the blood in Vertebrated animals.

439. These substances are contained, more or less abundantly, in most of the articles generally used as food; and where they are deficient, the animal suffers in consequence, if they be not supplied in any other way.—Thus common Salt exists, in no inconsiderable amount, in the flesh and fluids of animals, in the milk, and in the substance of the egg; it is not so abundant, however, in Plants; and the deficiency is usually supplied to herbivorous animals in some other way. Thus, salt is purposely mingled with the food of domesticated animals; and in most parts of the world inhabited by wild cattle, there are spots where it exists in the soil, and to which they resort to obtain it. Such are the "buffalo-licks" of North America.—*Phosphorus* exists also, in combination with albuminoid compounds, in all animal substances composed of these; and in the state of phosphate, combined with lime, magnesia, and soda, it exists largely in many vegetable substances ordinarily used as food. The phosphate of lime is particularly abundant in the seeds of the grasses; and it also exists largely, in combination with caseine, in Milk.—*Sulphur* is derived alike from vegetable and animal substances. It exists, in union with albuminoid compounds, in flesh, eggs, and milk; also in several vegetable substances; and, in the form of sulphate of lime, in most of the river and spring water that we drink.

440. *Lime* is one of the most universally diffused of all mineral bodies; for there are very few Animal or Vegetable substances in which it does not exist. The principal forms in which it is an element of Animal nutrition, are the carbonate and phosphate. Both these are found in the ashes of the grasses, and of other plants used as food; the phosphate of lime being particularly abundant in the corn-grains. The production of these cannot take-place, to their fullest extent, unless the soil previously contain phosphate of lime in a state in which the plant can receive it; and it is now understood that the diminished fertility of many lands is due, in great part, to the exhaustion of the soil as regards this ingredient. The restoration of the alkaline and earthy phosphates to the soil, in the form of manure, is the obvious means of preserving its fertility; but so long as a very large proportion of the excrements of animals (the materials of which are originally derived from the earth, through the vegetables it supplies) is allowed to run to waste, so long will it be necessary that the requisite amount of phosphate of lime should be drawn from foreign sources.

441. The phosphate of lime, as already mentioned, seems to perform important offices of a chemical nature in the animal economy, besides being the chief solidifying ingredient of bones and teeth; but the carbonate would seem principally destined to mechanical uses only; and we find it predominating, or existing as the sole mineral ingredient, in those non-vascular tissues of the Invertebrated animals, which give support and protection to their soft parts (§ 277). The degree of development of these tissues depends in great part upon the supply of carbonate of lime which the animals receive. Thus the Mollusca which inhabit the sea, find in its waters the proportion of that substance which they require; but those dwelling in streams and fresh-water lakes, which contain but a small quantity of lime, form very thin shells; whilst the very same species inhabiting lakes, which, from peculiar local causes, contain a large impregnation of calcareous matter, form shells of remarkable thickness.—The Crustacea, which periodically throw-off their calcareous envelope (§ 285), are enabled to renew it with rapidity by a very curious provision. There is laid-up in the walls of their stomachs a considerable supply of calcareous matter, in the form of little concretions, which are commonly known as "crabs' eyes." When the shell is thrown-off, this matter is taken-up by the circulating current, and is thrown-out from the surface, mingled with the animal matter of which the shell is composed. This hardens in a day or two, and the new covering is complete. The concretions in the stomach are then found to have disappeared; but they are gradually replaced, before the supply of lime they contain is again drawn-upon. The large amount of carbonate of lime which is required by the laying Hen, is derived from chalk, mortar, or other substances containing it, which she is impelled by her instinct to eat; and if the supply

of these be withheld, the eggs which she deposits are soft on their exterior,—not being destitute of shell, as commonly supposed,—but having the fibrous element of the shell (§ 181) unconsolidated by the intervening deposit of chalky particles.

2. *Of the Digestive Apparatus and its Actions in general.*

442. It has been already pointed-out, that the nature of the food of Animals is so far different from that of Plants, as to require the preparatory process of Digestion, before its nutritious part can be taken-up by the absorbent vessels and received into the system. This process may be said to have three different purposes in view; —the reduction of the alimentary matter to a fluid form, so that it may become capable of absorption;—the separation of that portion of it which is fit to be assimilated or converted into organized texture, from that which cannot serve this purpose, and which is at once rejected;—and the alteration, to a certain extent when required, of the chemical constitution of the former, which prepares it for the important changes it is subsequently to undergo. The simplest conditions requisite for the accomplishment of these purposes are the following;—a fluid capable of performing the solution, and of effecting the required chemical changes;—and a cavity or sac in which these operations may be performed.

443. In the lowest Animals, we find this cavity formed upon a very simple plan; the digestive sac being a mere excavation in the solid tissue of the body, lined with a membrane which is an inverted continuation of the external integument, and communicating with the exterior by one orifice only, through which food is drawn-in, and excrementitious matter rejected. In the little *Hydra*, or fresh-water Polype, the external covering of the body and the lining of the stomach correspond so closely in their structure,—their actions differing only with their situation, —as to be mutually convertible; for the animal may be turned completely inside-out, without its functions being deranged. The fluid necessary to dissolve the food, known by the name of 'gastric fluid' or 'gastric juice' is secreted in the walls of the stomach; and, from the transparency of the tissues, the whole process may be watched. The prey is frequently, and indeed generally, introduced alive, by the contractile power of the arms, which coil round it, and gradually draw it into the mouth or entrance to the digestive cavity; and its movements may often be observed to continue for some time after it has been swallowed. In a little while, however, its outline appears less distinct, and a turbid film partly conceals it; the soft parts are soon dissolved and reduced to a fluid state; and any firm indigestible portions which the body may contain, are rejected through the aperture by which it entered. The nutritive matter is absorbed by the walls of the digestive

cavity, every part of which appears to be endowed with equal power in this respect; and it is conveyed to the remoter parts of the arms by the simple imbibition of one part from another, without any proper circulation through vessels.

444. In the lowest Mollusks, however, which bear a strong resemblance in their general habits to zoophytes, the digestive cavity is provided with a second orifice; for, from the dilated cavity or stomach, an intestinal tube proceeds; and this has a termination distinct from the mouth, though often in its neighbourhood. The food, before entering the stomach, is submitted to a powerful triturating apparatus, resembling the gizzard of birds, by which it is broken-down; and in the digestive cavity it is submitted, not merely to the action of the gastric fluid, but also to that of the bile, which is secreted in little follicles in the walls of the stomach, and which is poured into its cavity during the process of digestion,—being easily recognized by its bright yellow colour. The excrementitious matter is rejected in the form of little pellets, through the intestinal tube.

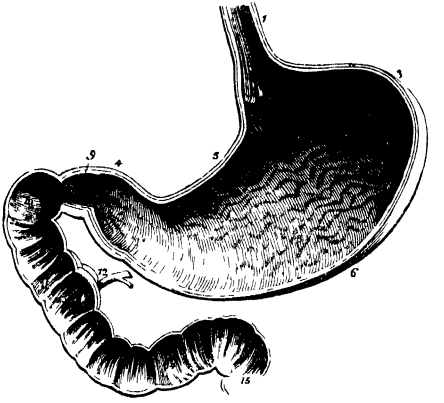
445. As we ascend the Animal scale, we find the digestive apparatus gradually increased in complexity; but its essential characters remain the same. Near the entrance to the stomach there is usually an apparatus for effecting the mechanical reduction of the food, by which its subsequent solution may be rendered more easy. This may consist of a set of teeth; either fixed in the mouth, as in Mammalia and Reptiles; or more particularly besetting the pharynx, as in Fishes; or attached to the walls of the stomach, as in Crustacea. Or it may be formed by the tongue, converted into a sort of rasp, as in the common Limpet, which thus reduces the sea-weeds that constitute its chief food. Or the the same purpose may be answered by a gizzard, or first stomach, with dense muscular and tendinous walls; such as we find in the grain-eating Birds and many Insects, and in certain Mollusks and Polypes. But where the food is already composed of very minute particles, or is received in a liquid state (as in the case of those animals which live upon the juices of others), or is easily acted-on by the gastric juice, no such preparation is requisite.

446. Before the food reaches the true digestive stomach, it is sometimes delayed in a previous cavity, in order that it may be macerated in fluid, and may be thoroughly saturated with it. This is the purpose of the *crop* of Birds, and of the first stomach of Ruminant animals (§ 457). When this incorporation with fluid is not effected before the food is subjected to the triturating process, it usually takes-place concurrently with it; and in those animals which reduce their food in the mouth by the process of mastication, there is a special secretion of fluid into that cavity for this purpose; this fluid is termed Saliva, and the act by which it is incorporated with the food is termed *insalivation*. The mechanical reduction of

the aliment, and its incorporation with fluid, constitute, as we shall hereafter see, a very important preparation for the *true digestive* process.

447. This process, among higher animals, takes-place exclusively, or nearly so, in the *Stomach;* the form of which varies with the character of the food. When this is of a nature to be easily acted-on by the gastric fluid, the stomach is a simple enlargement of the alimentary canal, almost in the direct line between the œsophagus and the intestinal tube; so that there is little provision for the delay of the food in its cavity. But when the aliment is such as to be less easily reduced, and requires to be submitted to the action of the gastric fluid for a longer period, the stomach forms a more

Fig. 77.*



* A vertical and longitudinal section of the Human Stomach and Duodenum, made in such a direction as to include the two orifices of the stomach — 1. The œsophagus; upon its internal surface the plicated arrangement of the cuticular epithelium is shown; 2. the cardiac orifice of the stomach, around which the fringed border of the cuticular epithelium is seen; 3. the great end of the stomach; 4. its lesser or pyloric end; 5. the lesser curve; 6. the greater curve; 7. the dilatation at the lesser end of the stomach, which has received from Willis the name of antrum of the pylorus, and which may be regarded as the rudiment of a second stomach; 8. the rugæ of the stomach formed by the mucous membrane; 9. the pylorus; 10. the oblique portion of the duodenum; 11. the descending portion; 12. the pancreatic duct and the ductus communis choledochus, close to their termination; 13. the papilla upon which the ducts open; 14. the transverse portion of the duodenum; 15. the commencement of the jejunum; in the interior of the duodenum and jejunum, the valvulæ conniventes are seen.

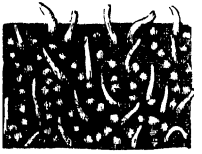
considerable enlargement, and is placed more out of the direct line between the œsophagus and the commencement of the intestine. The former condition obtains in the Carnivora, and particularly in those which live more upon blood than upon flesh,—such as Weasels, Stoats, &c., in which this part of the alimentary tube is almost straight; the latter condition is found among the Herbivora, and the provision for the delay of the aliment attains its greatest complexity in the Ruminant animals. The form of the Human stomach (Fig. 77) is intermediate between that of purely carnivorous and purely herbivorous animals. As in the former, there is a direct passage from the cardiac orifice, or entrance of the œsophagus, to the pyloric orifice or commencement of the intestine; but there is also a considerable dilatation or *cul de sac*, which is out of that line; and it appears that, during the digestive process, there is a constriction across the stomach, which separates the cardiac portion from the pyloric, and causes the retention of the food in the dilated part or large extremity. The gastric fluid is still secréted in the walls of this organ, by scattered follicles which pour their products into its cavity through separate orifices (§ 469); but the bile is elaborated by a distinct organ, altogether removed from it, which transmits its secretion by a single duct, that opens into the intestinal tube at a short distance from its commencement; and at the same point is delivered the pancreatic secretion, which, as we shall hereafter see (§ 480), takes an important share in the preparation of the alimentary products.

448. The action of the Stomach is restricted, in the higher animals, to the *reduction* of the food by the solvent powers of the gastric juice, and to the *absorption* (by the vessels in its walls) of those parts of it which are in a state of the most perfect solution. The changes which are produced by the admixture of the biliary and pancreatic fluids, take-place in the intestine; and the principal part of the nutritive elements of the food is taken-up by the absorbent vessels of the walls of the intestine, after that process has been accomplished. It would seem as if the preparation of the food for absorption were not by any means completed in this first portion of the alimentary canal; for it is still destined to pass through a long and convoluted tube, which is sometimes extended to an extraordinary degree; and in this passage it is gradually exhausted of its nutritious matter. The length of the intestinal canal bears a close relation to the character of the food. In the Carnivorous animals, whose aliment is easily dissolved and prepared for conversion into blood, the intestine is comparatively short; thus in the Lion and other Felines it is no more than three times the length of the body; and in some of the blood-sucking Bats, it is almost straight and simple. On the other hand, in Herbivorous animals it is of enormous length; thus in the Sheep it is about twenty-eight times as long as the body. In animals

whose diet is mixed, its length is intermediate between these extremes; thus in Man, the whole length of the intestinal tube is about thirty feet, or between five and six times that of the body. —The intestine is of much smaller diameter along its first portion, than it is nearer its termination; and it is consequently distinguished into the *small* and the *large*. In the small intestine, which constitutes in Man about five-sixths of the whole, the surface of the mucous membrane is greatly extended by the *valvulæ conniventes*, which are folds or duplicatures, often several lines in breadth, not entirely surrounding the intestine, but extending for about one-half or three-fourths of its circumference. These are wanting at the lower part of the ileum. The whole surface of the mucous membrane of the small intestine, below the entrance of the biliary ducts, is thickly covered with *villi*, or little root-like projections, in which the proper absorbent vessels originate. No proper valvulæ conniventes exist in the large intestine; the only extensions of the mucous membrane being crescentic folds at the edges of the sacculi or pouch-like dilatations in its walls; and the villi are comparatively few in number, gradually disappearing towards the termination of the intestine.

449. The mucous membrane of the alimentary canal, through its whole course, is studded with the orifices of numerous scattered glands, which lie in its thickness or immediately beneath it. The simplest of these are the follicles of Lieberkuhn, which are small pouches formed by an inflexion of the mucous surface, analogous to the follicles of other mucous membranes, and apparently destined for the elaboration of the protective secretion (§ 237, see Fig. 28, *b*). These follicles, in the small intestine, are very simple in their character, and not very deep; and their apertures, which are small, are situated for the most part around the bases of the villi. In the large intestine they are more prolonged, especially towards the extremity of the rectum, where they form a distinct layer, the component tubes of which are visible to the naked eye; they probably form the peculiarly thick and tenacious mucus of that part. These mucous follicles become particularly evident when the membrane is inflamed; for they then secrete an opaque whitish matter, which is absent in the healthy state, and which distinguishes their orifices (Fig. 78).—A modified kind of these follicles, rather more complex in structure,

Fig. 78.*



* Villous coat of Small Intestine, as altered in fever; the follicles of Lieberkühn filled with tenacious white secretion.

is found abundantly in the stomach; where they are concerned in the secretion of the gastric fluid (§ 469).

450. The coats of the intestine contain other glandulæ, of which some appear destined, like the preceding, to elaborate fluids of use in the system; whilst others may serve rather to draw-off from the blood certain products of decomposition, which are to be excreted from it. To the first of these categories the glands of Brunner (§ 480) probably belong; to the second, the large solitary follicles found in the large intestines. Besides the foregoing, the walls of the intestines contain a large number of peculiar bodies, known as the 'Peyerian glands;' these, however, have been determined by late researches to belong to the absorbent system, and to be assimilating rather than secreting organs (§ 496).

3. *Movements of the Alimentary Canal.*

451. The food which is conveyed to the mouth is laid-hold-of by the lips, by a muscular effort, which is voluntary in the adult under ordinary circumstances, but which may be performed automatically when the influence of the will is withdrawn; in the infant, as among the lower animals, the action seems purely automatic, the nipple of the mother being firmly grasped by the lips when introduced between them, even after the brain has been removed.—By the act of mastication, which then succeeds, the food is triturated and mingled with the salivary secretion; and is thus prepared for the further process of solution, to which it is to be subjected in the stomach. The degree of this preparation, and the form of the instruments by which it is effected, vary in different animals, according to the nature of the food. In those Carnivora whose aliment consists exclusively of flesh, very little mastication is necessary, because this substance is very readily acted-on by the gastric fluid; and we accordingly find the molar teeth raised into sharp cutting edges, and working against each other with a scissors-like action (the only one permitted by the articulation of the jaw), so as simply to divide the food. On the other hand, in those Herbivora whose food consists of tough vegetable substances, such as the leaves of grasses, or the stems and roots of other plants, we find the molar or grinding teeth peculiarly adapted to its reduction; their surface being extended horizontally, and being kept continually rough by the alternation of vertical plates of different degrees of hardness; and the lower jaw being so connected with the skull, that great freedom of motion is permitted. In Man we find an intermediate conformation, as regards both the teeth and the articulation of the jaw; for the molar teeth possess broad surfaces, which are covered with a continuous coat of enamel, but which are raised into rounded tubercles; and the articulation of the jaw allows it a degree of freedom which is much greater than that

possessed by the Carnivora, although inferior to that which exists in many Herbivora. The whole apparatus of Mastication is so formed in Man, as to lead to the conclusion that he is destined to live on a mixed diet, composed in part of animal flesh, and in part of vegetable substances that are sufficiently soft to be reduced by the simple act of crushing, or by the slight trituration for which the molar teeth are adapted.

452. The mechanical reduction of the food by Mastication, and the incorporation of the Salivary secretion with its substance, constitute a very important step in the Digestive process. We shall hereafter see that the operations to which the alimentary matter is subjected in the stomach, are of a purely Chemical nature; and this preparation is exactly of the same character as that which the Chemist finds it advantageous to make, when he is operating on a substance of difficult solution. For nothing is so favourable to the action of the solvent, as the previous reduction of the matter to be dissolved, and its thorough incorporation with the fluid that is to act upon it. We shall hereafter see that the relative properties of the Saliva and of the Gastric fluid are such, that, by the minute admixture of the food with the former, the latter finds access to every particle of it. Hence the practice of eating so rapidly that Mastication and Insalivation are insufficiently performed, is extremely injurious; since it throws more work upon the Stomach than it ought to perform, by rendering its solvent action more difficult. There can be no doubt that, by the prolonged continuance of it, a foundation is laid for the distressing complaint termed Dyspepsia, or difficulty of digestion; and where any form of this complaint exists, too much attention cannot be paid to the efficient reduction of the food in the mouth.

453. When the aliment has been sufficiently triturated, it is conveyed into the Pharynx by the act of *Deglutition* or swallowing. This act involves a great many distinct movements, into a minute description of which we shall not here enter; but it is desirable that its general nature should be well understood. It is one of those most purely *reflex* in its character (§ 394), and is not capable of being performed or even controlled by a voluntary effort. This statement may seem inconsistent with the fact, that we swallow when we will; but it is not so in reality. The muscular movements which are concerned in deglutition, are called-forth by nerves that proceed from the spinal cord, not from the brain; these motor nerves are excited to action by the contact of solid or fluid matters with the mucous surface of the fauces, and in no other way. The impression produced by the contact is conveyed to the *Medulla Oblongata*, or that portion of the spinal cord which lies within the cranium, by afferent nerves that terminate in it; and, in immediate respondence to that impression, a motor impulse is transmitted from it, which calls the muscles into the combined action

necessary to produce the movement. Now this contact *also* produces a sensation, provided the brain be sound and awake, because nervous fibres proceed from the mucous surface to the brain as well as to the spinal cord; but this sensation is not a necessary link in the chain of actions by which the movement is produced; for the act of Deglutition takes-place during profound sleep, when all sensation is suspended, and it may be excited even after the brain has been removed. It *seems* to be voluntary, under ordinary circumstances, simply because it is by an act of the will that the matter to be swallowed is carried backwards into contact with the fauces; but that it is not so in reality, is shown by the fact, that when this impression has once been made with sufficient force, we cannot by any effort of the will prevent the action. We have a good example of this in the following circumstance, of no very unfrequent occurrence. The tickling of the upper part of the fauces with a feather is often practised to induce vomiting; but if the end of the feather be carried too low down, it excites the act of deglutition instead; the feather is grasped by the pharynx and drawn downwards; and if it be not held tenaciously between the fingers, it is drawn from them and carried downwards into the stomach.

454. The carrying-back of the alimentary matter, so that it reaches the fauces or upper part of the pharynx, is principally accomplished by the tongue; when it has passed the interior palatine arches, these contract and close over the tongue, so as to prevent the return of the food into the mouth; and at the same time the posterior palatine arches and the uvula are so drawn-together, as to prevent its passage into the posterior nares. The larynx is drawn forwards beneath the root of the tongue, and the epiglottis is pressed-down over the rima glottidis, so that nothing can enter the latter, unless drawn towards it by an act of inspiration. When fairly within the pharynx, the alimentary matter is seized by the constrictors which enclose that part of the alimentary tube, and is drawn downwards by them into the œsophagus, which is the cylindrical continuation of it. The continued action of the constrictors serves to propel the food along the œsophagus; their movement being of a reflex nature, excited by the contact of the substance contained in the tube with its lining membrane,—which produces an impression that is transmitted to the medulla oblongata, and is reflected-back as a motor impulse to the muscles. We have here a distinct case of reflex action without sensation; for we have no consciousness of the ordinary passage of food down the œsophagus, unless it occasion pressure on the surrounding parts through its bulk, or unduly irritate the lining membrane by its high or low temperature or its acrid qualities; and yet it may be shown by experiment, that the completeness of the nervous circle is requisite for the excitement of the movement, which will not take-place when

it is interrupted either by division of the nerves, or by destruction or paralysis of the medulla oblongata.

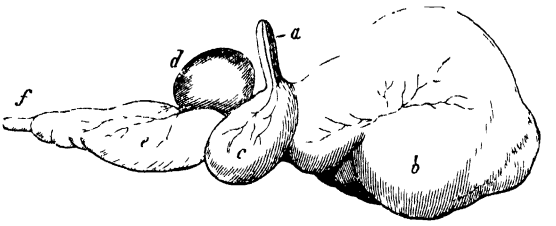
455. The progress of the food along the Œsophagus is aided by the action of the muscular coat peculiar to it. This is composed of the non-striated fibre; and, like that of the intestinal canal further on, it is usually stimulated to contraction by the *direct contact* of the stimulus, and not either by the will, or by the reflex action of the spinal cord. The movement produced by it is of the *peristaltic* or wave-like kind; the contractions being limited to one portion of the tube, and being propagated along it from above downwards. This action continues after the division of all the nerves supplying the œsophagus; and it cannot, therefore, be dependent upon the brain or spinal cord. It may be observed to take-place in a rhythmical manner (that is, at short and tolerably regular intervals), whilst a meal is being swallowed; but as the stomach becomes full, the intervals are longer and the wave-like contractions less frequent. The degree in which the action of the œsophagus alone, without that of the surrounding muscles, is capable of propelling the food into the stomach, seems to vary in different animals. When the latter are paralysed in the Dog, by section of the nerves that supply them, the food that has entered the œsophagus is still propelled into the stomach; but this is not the case in the Rabbit, the action of its œsophageal fibres not being sufficient to carry the food onwards to the stomach, though it will expel it from the divided extremity of the tube when it is cut across. The usual peristaltic movements of the œsophagus are reversed in Vomiting; and this reversion has been observed, even after the separation of the stomach from the œsophagus, as a consequence of the injection of tartar emetic into the veins.

456. At the point where the œsophagus enters the Stomach,—the cardiac orifice of the latter,—there is a sort of sphincter, or circular muscle, which is usually closed. This opens when there is a sufficient pressure on it, made by the accumulated food propelled by the movements of the œsophagus above; and it then closes again, so as to retain the food in the stomach. The closure is due to reflex action; for when the nerves supplying it are divided, the sphincter no longer contracts, and the food regurgitates into the œsophagus. The opening of the cardia is one of the first acts which takes-place in vomiting.

457. In Ruminating animals, there is a very remarkable conformation at the lower end of the œsophagus, which is destined to regulate the passage of food into the different compartments of the stomach, according as it has been submitted to the second mastication, or not. The œsophagus (Fig. 79, *a*) does not terminate at its opening into the first stomach or paunch (*b*), but it is continued onwards as a deep groove with two lips (Fig. 80): by the closure of these lips it is made to form a tube, which serves to convey the

food onwards into the third stomach; but when they separate, the food is allowed to pass either into the first or the second stomachs. When the food is first swallowed, it undergoes but very little masti-

Fig. 79.*

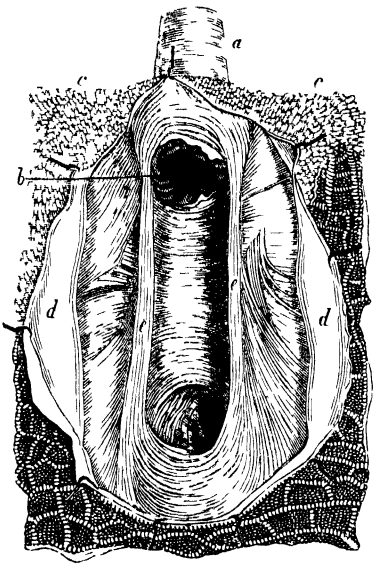


cation; it is consequently firm in its consistence, and is brought down to the termination of the œsophagus in dry bulky masses. These separate the lips of the groove or demi-canal (Fig. 80, *e*, *e*), and pass into the first and second stomachs. After they have been macerated in the fluids of these cavities, they are returned to the mouth by a reverse peristaltic action of the œsophagus; this return takes place in a very regular manner, the food being shaped into globular pellets by compression within a sort of mould formed by the demi-canal, and these pellets being conveyed to the mouth at regular intervals, apparently by a rhythmical movement of the œsophagus. It is then subjected to a prolonged mastication within the mouth (the 'chewing of the cud'), by which it is thoroughly triturated and impregnated with saliva; after which it is again swallowed in a pulpy semi-fluid state. It now passes along the groove which forms the continuation of the œsophagus, without opening its lips; and is thus conveyed into the third stomach (Fig. 79, *d*), whence it passes to the fourth (*e*), in which alone the true digestive process takes-place. Now, that the condition of the food as to bulk and solidity, is the circumstance which determines the opening or closure of the lips of the groove, and which consequently occasions its passage into the first and second stomachs, or into the third and fourth, appears from the experiments of Flourens; who found that when the food, the first time of being swallowed, was artificially reduced to a soft and pulpy condition, it passed for the most part along the demi-canal into the third stomach, as if it had been ruminated,—only a small portion finding its way into the first and second stomachs. How far the actions of this curious

* Compound Stomach of Sheep —*a*, œsophagus; *b*, paunch; *c*, second, or honeycomb stomach; *d*, third stomach, or many-plies; *e*, fourth stomach, or reed; *f*, pylorus.

apparatus are dependent upon nervous influence,—or how far they are due to the exercise of the contractility of the muscular fibre, directly excited by the contact of the substances with the lining

Fig 80 *



membrane of the tubes and cavities,—has not yet been clearly ascertained.

458. The food, when introduced into the Stomach, and submitted to the solvent action of its secretions, is also subjected to a peculiar movement, which is effected by the muscular walls of that organ. The purpose of this motion is obviously to keep the contents of the stomach in that state of constant agitation, which is most favour-

* Section of part of the Stomach of the Sheep, to show the demi-canal of the Œsophagus, the mucous membrane is for the most part removed, to show the arrangement of the muscular fibres. At *a* is seen the termination of the œsophageal tube, the cut edge of whose mucous membrane is shown at *b* The lining of the first stomach is shown at *c*, *c*, and the mucous membrane of the second stomach is seen to be raised from the subjacent fibres at *d*. At *e*, *e*, the lips of the demi-canal are seen bounding the groove, at the lower end of which is the entrance to the third stomach or many-plies.

able to their chemical solution; and particularly to bring every portion of the alimentary matter into contact with the walls of the stomach, so as to be subjected to the action of the fluid which is poured-forth from them during the digestive process. The movement is produced by the alternate shortening and relaxation of the various fasciculi, which are disposed in almost every direction throughout the muscular wall of the stomach; and it seems to produce a kind of revolution of the contents of the stomach, sometimes in the direction of its length, and sometimes transversely. Its result is well shown in the hair-balls, which are occasionally found in the stomachs of animals that have swallowed hair from time to time through licking their skins; the component hairs not being pressed into a confused mass, but being worked together in regular directions, and so interwoven that they cannot be readily separated. As digestion proceeds, the dissolved fluid escapes, little by little, through the pyloric orifice, which closes itself firmly against the passage of solid bodies; and this motion continues until the stomach is completely emptied; when it ceases, until food is again introduced. The bulk of the alimentary mass diminishes rapidly, as the solvent process is near its completion; and the separation of the fluid product or chyme is aided by a peculiar action of the transverse fasciculi, which surrounds the stomach at about four inches from its pyloric extremity. These shorten in such a manner as to produce a sort of hour-glass separation between the portions of the stomach on either side of it; and the fluid solution, being received by the pyloric or smaller portion, is pumped-away through the pylorus; whilst the solid matter yet undissolved is retained in the larger division.

459. The degree in which these movements are dependent upon the nervous system, or are under its control or direction, has not yet been clearly ascertained. Distinct movements may be excited in the stomach of a Rabbit, if it be distended with food, by irritating the par vagum soon after the death of the animal; these movements seem to commence from the cardiac orifice, and then to spread themselves peristaltically along the walls of the stomach; but no such movements can be excited if the stomach be empty. On the other hand, there is distinct proof that all the movements necessary to digestion may take-place after the section of that nerve, although the first effect of the operation appears to be to suspend them completely. It is probable that the movements of the stomach are more regular and energetic in Herbivorous animals, whose food is difficult of digestion, than they are in the Carnivora, whose aliment is dissolved with comparative facility.

460. From the time that the ingested matter enters the Intestinal tube, it is propelled onwards by the peristaltic contractions of its muscular coat; which are excited, independently of all nervous influence, by the contact of the aliment, or by that of the secretions

mingled with it in its passage along the canal. These last appear to have an important effect; for we find that, when the bile-duct is tied, so as to prevent the bile from entering the intestine, constipation always occurs; whilst an increase of the biliary and other secretions, consequent upon the action of mercury or upon any other cause, produces an increased peristaltic movement, and a more rapid discharge of the excrementitious matter. During the passage of the alimentary matter along the small intestine, as we shall see hereafter, a large proportion of its fluid is removed by the absorbent power of the villi; and the residue is again brought, therefore, to a more solid consistence. This residue consists in part of those portions of the aliment, which are not capable of being dissolved or finely divided, so as to be received by the absorbents; and in part of the matters poured into the alimentary canal, by the various glands that discharge their contents into it, for the purpose of being carried out of the body. The fæces, which are thus formed, are propelled through the large intestine, by the continued peristaltic action of its walls, until they arrive at the rectum.

461. That the ordinary peristaltic action of the intestinal canal is independent of nervous influence, is sufficiently indicated by the fact, that it will continue when the tube is completely separated from all connection with the nervous centres; as well as by the difficulty already adverted-to (§ 353) of exciting contractions in the muscular coat by any stimulation of its nerves. All the nerves of the intestine, from its commencement at the pyloric orifice of the stomach to its termination at the anus, are derived from the ganglia of the Sympathetic system; but there is evidence that those which influence its movements are really derived from the Spinal Cord (see CHAP. XII.). Although the *will* has no influence whatever on the peristaltic movement, yet the *emotions* seem to affect it; and it is probably to convey their influence, that the intestinal canal is supplied with motor nerves. It is also furnished with sensory nerves, which form part of the trunks of the sympathetic system, but which really pass onwards to the brain; these do not, however, make us conscious of the passage of the alimentary matter along the canal, so long as it is in a state of health; but in various diseased conditions, they give rise to sensations of the most painful nature.

462. For the occasional discharge of the fæces from the rectum, and for the retention of them at other times, we find the outlet or anal orifice provided with an additional muscular apparatus, which is connected with the spinal system of nerves. The act of Defecation is due to the pressure upon the contents of the rectum, which is occasioned by the combined contraction of the diaphragm and the abdominal muscles; whilst, on the other hand, the retention of the fæces is due to the contractile power of the sphincter muscle which surrounds the anus. The action of the sphincter ani, like that of the sphincter of the cardia, is a reflex one; dependent upon the

connection of the muscle, by excitor and motor nerves, with the spinal cord. If the lower portion of the cord be destroyed, or if the nerves be divided, the sphincter loses its contractile power, and becomes flaccid. When in proper action, however, its power is sufficient to prevent the escape of the contents of the rectum; until the expulsive force becomes very strong, in consequence either of the quantity of fæces which have accumulated, or the acridity of their character. In either case, the impression made upon the mucous membrane of the rectum is conveyed to the spinal cord; and, by a reflex motor impulse, the muscles of defecation are thrown into combined action, the resistance of the sphincter is overcome, and the fæces are expelled. An unduly-irritable state of the mucous membrane, or a disordered state of the excrementitious matter (resulting from the irritating character of the substances swallowed, from the acrid character of the secretions poured into the canal, or from an unusual change in the aliment during the digestive process), may occasion unduly-frequent calls upon the muscles of defecation, which the sphincter is unable to resist. On the other hand, if the progress of the fæces be delayed in the large intestine, by deficient peristaltic movement, they accumulate higher up, and the act of defecation is not excited.

463. Although the sphincter ani on the one hand, and the muscles of defecation on the other, are called into action by the reflex power of the spinal cord, and are so far involuntary in their operation, yet they are also in some degree subject (in Man at least) to the influence of the will. The resistance of the sphincter may be increased by a voluntary effort, when it is desired to retain the fæces in opposition to the power of the expulsors; and it is only when the latter operate with excessive force, that they can overcome it. On the other hand, the expulsors may be called into action, or may be aided, by the will, when the stimulus to their movement received through the spinal cord would not otherwise be strong enough; and the fæces may thus be evacuated by a voluntary effort, at a time when they would not else be discharged.

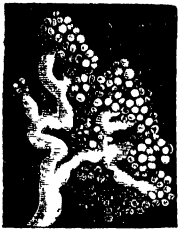
4. *Of the Secretions poured into the Alimentary Canal, and of Changes which they effect in its contents.*

464. The whole Mucous Membrane of the Alimentary canal, from the mouth to the anus, is covered during health with that peculiar viscid secretion termed *mucus*, of which the characters have been already described (§ 237). This is formed, partly, on the free surface of the membrane itself, but chiefly in the numerous follicles or depressions by which that surface is increased (§ 449); and it appears destined for the protection of the delicate highly-vascular membrane from undue irritation, by the contact of the substances which are passing through the alimentary tube. When

these are unusually acrid, the secretion of mucus is augmented in quantity, and is increased in viscidity, so as to form an effective sheath to the membrane, which would otherwise suffer severely. When this secretion is deficient, the membrane is irritated by the contact of any but the blandest substances; and the class of remedies termed *demulcents* are useful in coating and protecting it.

465. During the mastication of the food in the mouth, the *Salivary* secretion is poured-in, for the purpose of being mingled with it, and of rendering the act of mastication more easy. This secretion is formed by three pairs of glands,—the Parotid, the Sub-lingual, and the Sub-maxillary; these are composed of minute follicles, whose diameter is about 1-1000th of an inch, connected together by branches of their duct, upon which they are set like grapes upon their stalk (Fig. 81), surrounded by a plexus of blood-vessels (Fig. 15), and bound-together by areolar tissue. Within the follicles are the true secreting cells (§ 238); by whose growth and development the material of the secretion is separated from the blood. These salivary cells are often to be recognized in the saliva; they must not, however, be confounded with the epithelium-cells of the mucous membrane of the mouth, which are much larger. The fluid obtained from the mouth is not pure saliva; for the mucus of the mouth itself is mingled with the secretion from the salivary glands. If the proportion of the former be considerable, it gives to the fluid of the mouth a slightly-acid reaction; whilst, if the latter be predominant (which it is directly before, and during, the act of eating), the fluid of the mouth has an alkaline reaction. It may be sometimes observed that the saliva of the mouth will strike a blue colour with reddened litmus-paper, whilst it turns blue litmus-paper red; thus showing the presence both of an acid and an alkali in a state of imperfect neutralization.

Fig. 81.*



466. The solid matter of the Salivary secretion, taken as a whole, is about ½ per cent.; and is composed in part of animal principles, and in part of saline substances. The animal matter consists of mucus with a peculiar substance termed *ptyaline* or salivary matter, which is soluble in water and insoluble in alcohol, and which appears to have a decided effect in producing the metamorphosis of certain alimentary substances, on which it acts like a *ferment*, converting starch into sugar, and sugar into lactic acid. Its chemical nature

* Lobule of Parotid Gland of new-born infant, filled with mercury; magnified 50 diameters.

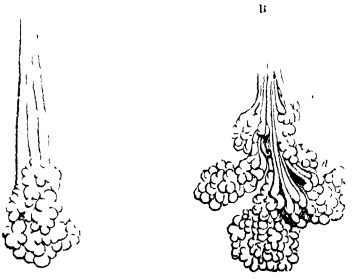
has not yet been precisely determined; but it seems to be a derivative of albumen. The saline constituents of the Saliva are nearly identical with those of the blood; the chlorides of sodium and potassium form about half; and the remainder consists chiefly of the tribasic phosphate of soda, to which the alkaline reaction of the fluid is due, with the phosphates of lime, magnesia, and iron. It is of the earthy phosphates that the *tartar* which collects about the teeth is chiefly composed, the particles of these being held together by about 20 per cent. of animal matter; and the composition of the concretions which occasionally obstruct the salivary ducts, is nearly the same.—It appears, however, from recent observations, that the products secreted by the several Salivary glands are by no means identical. The fluid of the parotid and sublingual glands is clear, limpid, and thin as water, and contains but a small proportion of solid matter; that of the submaxillary, on the other hand, is thick and viscid, resembling ordinary simple syrup in colour and consistence, and containing a far larger proportion of solid matter. The former liquid is secreted most abundantly during mastication, and seems especially destined to saturate the food; the latter is poured-forth most copiously just as the masticated bolus is being swallowed, and seems destined to facilitate the act of deglutition. What is the relative transforming power of these two liquids, has not been conclusively ascertained; but it seems beyond doubt that the activity of the proper salivary secretion is greatly augmented by admixture with the mucus of the mouth, which must consequently be regarded as a very important constituent of the buccal saliva.

467. The quantity of Saliva formed during the twenty-four hours, has been estimated by Bidder and Schmidt at not less than 56 oz., containing 233 grs. of solid matter; on this point, however, it is impossible to speak with certainty. The secretion is by no means constantly flowing; indeed it is almost entirely suspended when the masticator muscles and tongue are at perfect rest, unless it be excited by any mental cause; and hence it is that the mouth becomes dry during sleep, if it be not kept closed. The flow of Saliva takes-place just when it is most wanted; that is, when food has been taken into the mouth, and when the operation of mastication is going-on. But it will also take-place, especially in a hungry person, at the sight, or even at the idea, of savoury food; as is implied by the common expression of the 'mouth watering' for such an object. The influence thus exercised over it seems to be conveyed to the salivary glands by the Fifth and Facial Nerves; for it has been found by Ludwig that section of the Facial nerve entirely suspends the secretion of the Parotid gland, save in so far as this is kept-up by the indirect action of the Fifth pair and of the Glosso-pharyngeal, through the stimulus afforded by the movements of mastication and deglutition; whilst the secretion of the Submaxillary gland is suspended by section of the Fifth and Facial.

468. Having been conveyed into the Stomach, the food is submitted to the action of the 'gastric juice,' which is secreted in the walls of that organ. This fluid is not present in the empty stomach; its secretion being excited by the presence of food, or by the irritation of the walls of the organ by some solid body. In the intervals between the digestive process, the mucous membrane is of a light pink hue; but it becomes more turgid with blood, when the presence of food calls for the activity of its secreting processes. It is of a soft and velvet-like appearance; and it is constantly covered with a very thin transparent viscid mucus, which has neither acid nor alkaline reaction. By applying aliment or other stimulants to the internal coat of the stomach, and by observing the effect through a magnifying glass, numerous minute papillæ can be seen to erect themselves upon the mucous membrane, so as to rise through the coating of mucus; and from these is poured-forth a pure, limpid, colourless, slightly viscid fluid, having a distinctly-acid reaction, which is the Gastric juice. This fluid is secreted by follicles which are lodged in the walls of the stomach, and which closely resemble those that elsewhere secrete mucus; but they are usually of more complex structure, and are more numerous.

469. If the Mucous Membrane of the stomach be divided by a section perpendicular to its walls, it is seen to be made-up, as it were, of tubular follicles closely applied to each other; their blind extremities resting upon the submucous tissue, and their open ends being directed towards the cavity of the stomach. In some situations, these tubuli are short and straight; in other parts they are longer, and present an appearance of irregular dilatation or partial convolution (Fig. 82, A). This is their usual character, especially near the cardiac orifice of the stomach; but near the pyloric orifice

Fig. 82.*



* Glandulæ from the coats of the Stomach, magnified 45 diam.;—A, from the middle of the stomach; B, from the neighbourhood of the pylorus.

they have a much more complex structure (Fig. 82, B). These tubular follicles are arranged in bundles or groups (Fig. 83, *b*), and are surrounded and bound-together by a fine areolar membrane (*a*); and this also serves to convey vessels from the submucous tissue, which ramify among the follicles, and supply the materials for their secretion. The number of tubuli in each group is by no means constant. The follicles do not, in general, open directly upon the surface; but into the bottom of small depressions or pits, which may be seen to cover the membrane (Fig. 84). These pits are more or less circular in form; and are separated from one another by membranous partitions of variable depth, and sometimes by pointed processes which seem like rudimentary villi. The diameter of these pits varies from about 1-100th to 1-250th of an inch; it is always greatest near the pylorus. The number of the gastric follicles opening into each, is usually from three to five; but there are sometimes more.

Fig. 83.*

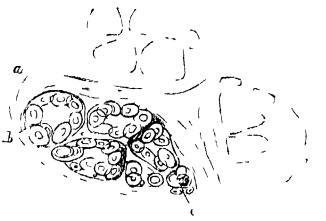
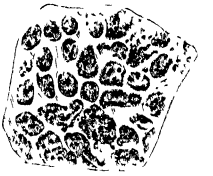


Fig. 84 †



470. The chemical composition of the Gastric juice has been a subject of much discussion, and can scarcely yet be regarded as precisely determined: possibly it may vary in its nature, according to the state of the system, and the kind of animal from which the fluid is obtained. In all cases, however, this fluid appears to contain a free acid, together with a peculiar organic compound, *Pepsin*, which seems like albumen in a state of change. It is in regard to the nature of the free acid, that Chemists are most at issue. Hydrochloric, phosphoric, acetic, lactic, and butyric acids, have each been detected in the gastric fluid; but there are great difficulties in the way of determining which of these acids are free, and which are in combination. Thus, although it is very easy to obtain free hydro-

* Transverse section of cluster of Gastric glandulæ;—*a*, areolar tissue bounding clusters; *b*, one of the tubular follicles; *c*, contained cells.

† Portion of the surface of the Mucous Membrane of the Stomach, showing the pits into which the Gastric follicles open.

chloric acid by distillation of the gastric fluid, yet this is by no means an adequate proof of the previous presence of the acid in a free state; for it has been found that free lactic acid will decompose chloride of sodium at an elevated temperature, forming (with water) lactate of soda and hydrochloric acid; so that the lactic may be the free acid of the gastric fluid, the hydrochloric having been formed during the distillation, at the expense of the chloride of sodium, which is a constituent of the gastric fluid. It has been further determined that hydrochloric and lactic acids both possess a remarkable solvent power for albuminous matters, when assisted by pepsin; so that it is probable that they may replace one another. —The properties of the organic compound, named Pepsin, which is peculiar to the gastric fluid, have been principally studied in that form of it obtained from the mucous membrane of the stomach of the Pig, which bears a close resemblance to that of Man. When this membrane is digested in a large quantity of *warm* water, it is purified from the various soluble substances it may contain; but the pepsin is not taken-up, as it is not soluble in warm water. By continuing the digestion in *cold* water, the pepsin is then extracted nearly pure. When this solution is evaporated to dryness, there remains a brown, greyish, viscid mass, having the appearance of an extract, and the odour of glue. A similar substance may be obtained by adding strong alcohol to a fresh solution of pepsin; for the latter is then precipitated in white flocks, which may be collected on a filter and produce a grey compact mass when dried. Pepsin enters into chemical combination with many acids; forming compounds which still redden litmus-paper; and this appears to be its condition in the gastric juice.

471. The muriate and acetate of pepsin possess a very remarkable solvent power for albuminous substances. A liquid which contains only 17 ten-thousandths of acetate of pepsin, and 6 drops of hydrochloric acid per ounce, possesses solvent power enough to dissolve a thin slice of coagulated albumen, in the course of six or eight hours' digestion. With 12 drops of hydrochloric acid per ounce, the same quantity of white-of-egg is dissolved in two hours. A liquid which contains only half a grain of acetate of pepsin, and to which hydrochloric acid and white-of-egg are alternately added, so long as the latter is dissolved, is capable of taking up 210 grains of coagulated white-of-egg, at a temperature between 95° and 104°. The same acid with pepsin dissolves blood, fibrin, meat, and cheese; whilst the acid without the pepsin requires a very long time to do so at ordinary temperatures. Very dilute hydrochloric acid, however, at the boiling point, dissolves these albuminous substances; and the solution has the same character as that which is made by the agency of pepsin. The horny tissues, such as the epidermis, horn, hair, &c., and the yellow fibrous tissue, are not affected by the acid solution of pepsin.—It appears from these experiments, that

the acid is the real solvent; and that the action of the pepsin is limited to *disposing* the albuminous matter for solution, producing in it a change analogous to that which may be effected by heat. Hence it may be considered, like ptyalin, as a sort of *ferment;* its office being to produce a tendency to change in the substances on which it acts, without itself entering into new combinations with any of their elements.

472. These experiments appear to afford an explanation of the properties of the gastric fluid, as ascertained by direct experiment upon it. When drawn direct from the human stomach, it is found to possess the power of dissolving various kinds of alimentary substances, whilst these are submitted to its action at a constant temperature of 100° (which is about that of the stomach), and are frequently agitated. The solution appears to be in all respects as perfect as that which naturally takes-place in the stomach; but a longer time is required to make it. This is easily accounted-for by the difference of the conditions; for no ordinary agitation can produce the same effect with the curious movements of the stomach (§ 458); fresh gastric fluid is poured-out, as it is wanted, during the natural process of digestion; and the continual removal of the matter which has been already dissolved, by its exit through the pylorus, is of course favourable to the action of the solvent upon the remainder. The quantity of food which a given amount of gastric fluid can dissolve, is limited; precisely as in the case of the acidulous solution of pepsin. The marked influence of temperature upon its action is shown by the fact, that fresh gastric fluid has scarcely any influence on the matter submitted to it, when the bottle is exposed to cold air, instead of being kept at a temperature of 100°. Hence the use of a large quantity of cold water at meal-times, or of ice afterwards, must retard the digestive process.

473. The pulpy substance, which is the product of the reducing action of the gastric juice, is termed *Chyme*. Its consistence will of course vary, in some degree, with the relative quantity of solids and liquids ingested. In general it is greyish, semifluid, and homogeneous; and possesses a slightly acid taste, but is otherwise insipid. When the food has been of a rich oily character, the Chyme possesses a creamy aspect; but when the food has chiefly consisted of farinaceous matter, it has rather the appearance of gruel. The state in which the various alimentary principles exist in it, has not yet been accurately determined; the following, however, may be near the truth.—The Albuminoid compounds, whether derived from Animal or Vegetable food, are all reduced to a state of solution, if the gastric digestion have been properly performed; and in this state, they have all the properties of Albumen.—Gelatine will be dissolved or not, according to its previous condition; if it exist in a tissue from which it cannot readily be extracted, it will pass-forth

almost unchanged; but when ingested in a state of solution, it remains so; and if it have been previously prepared for solution by boiling, its solution is completed in the stomach. Its condition, however, is altered in the process; for it loses the power of gelatinizing, and cannot be precipitated by chlorine; so that it cannot be detected as such either in the blood or the chyle into which it is received.—The Gummy matters of Vegetables are dissolved, when they exist in a soluble form; as in the case of pure gum, pectin, and dextrin or starch-gum. It does not appear, however, that any further conversion of Starch is effected by the gastric fluid; for if no saliva be admitted into the stomach, no sugar is generated there by the metamorphosis of the starch which it may contain. But the continued introduction of the saliva ordinarily occasions the continuance of the process, although the presence of the free acid of the gastric fluid in some degree interferes with it; and it is not until this has been neutralized by the admixture of the biliary and pancreatic secretions, that the metamorphosis of the starch is actively renewed. Any sugar that may have been taken-in as such, or that may have been produced from starch by the converting power of the saliva, is reduced to the state of complete solution.—Oily matters do not appear to be in any way acted-upon, otherwise than by being set-free by the solution of the envelopes which may have contained them (*e. g.* fat-cells), and by being dispersed through the mass; their state of division, however, does not seem to be yet fine enough to allow of their absorption.—Most other substances, as resins, woody fibre, horny matter, yellow fibrous tissue, &c., pass unchanged from the stomach, and undergo no subsequent alteration in the intestinal canal; so that they are discharged among the fæces as completely useless.

474. We have now to notice the conditions under which the Gastric fluid is secreted; the knowledge of which is of great practical importance. We have seen that it is not poured-forth, except when food is introduced into the stomach, or when its walls are irritated in some other mode; and there is reason to believe that it is not previously secreted and stored-up in the follicles, but that the act of secretion itself is due to the stimulus applied to the mucous membrane. The quantity of the fluid then poured into the stomach, however, is not regulated by the amount of food ingested, so much as by the wants of the system; and as only a definite quantity of food can be acted-on by a given amount of gastric juice, any superfluity remains undissolved for some time,—either continuing in the stomach until a fresh supply of the solvent is secreted, or passing into the intestinal canal in a crude state, and becoming a source of irritation, pain, and disease. The use of a small quantity of salt, pepper, mustard, or other stimulating substances, appears to produce a gently-stimulating effect upon the mucous membrane, and by causing an increased afflux of blood, to

augment the quantity of the gastric fluid poured-forth. Any excess of these or other irritants, however, produces a disordered condition of the mucous membrane, which is very unfavourable to the digestive process. It becomes red and dry, with an insufficient secretion of mucus; the epithelial lining is abraded, so that the mucous coat is left entirely bare; and irregular circumscribed patches of a deeper hue, sometimes with small aphthous crusts, present themselves here and there on the walls of the stomach. Similar results follow excess in eating. When these changes are inconsiderable, the appetite is not much impaired, the tongue does not indicate disorder, and the digestive process may be performed; but if they proceed further, dryness of the mouth, thirst, accelerated pulse, foulness of the tongue, and other symptoms of febrile irritation, manifest themselves; and no gastric secretion can then be excited by the stimulus of food. Similar results may follow the excitement of the emotions; and those of a depressing nature seem especially to produce a pale flaccid condition of the mucous membrane, which is equally unfavourable to the due secretion of gastric fluid.—The Pneumogastric nerve seems most probably to be the channel through which mental emotions affect this process; since experiment shows that section of it (on both sides) usually has the effect of suspending the secretion for a time. If, however, the life of the animal be sustained long enough, there is adequate evidence that the secretion may be renewed; so that it cannot be dependent, as some have maintained that it is, upon nervous agency.—The quantity of gastric fluid ordinarily secreted by a healthy adult, in the course of every twenty-four hours, is estimated by Bidder and Schmidt at as much as from 14 to 17 *pounds*, containing about 6 *ounces* of solid matter: other estimates, however, place it at not more than one-fourth of that amount.

475. That the quantity of the secretion is ordinarily proportioned to the wants of the system,—that the introduction of any superfluous aliment into the stomach is not only useless but injurious, as giving rise to irritation,—that incipient disorder of the stomach may occur, rendering it less fit than usual for the discharge of its important duties, without manifesting itself by the condition of the tongue,—that when the tongue *does* indicate disorder of the stomach, such disorder is usually considerable,—and that every particle of food ingested, in such states as prevent the secretion of gastric fluid, is a source of fresh irritation,—are truths which cannot be too constantly kept in mind. There can be no doubt that the habit of taking more food than the system requires, is a very prevalent one; and that it is persevered-in, because no evil result *seems* to follow. But when it is borne in mind that this habit must keep the stomach in a state of continual irritation, however slight, it can scarcely be doubted that the foundation is thus laid for future disorder of a more serious kind. Two

circumstances especially tend to maintain this practice in adults, independently of the mere disposition to gratify the palate. One is the habit of eating the same amount of food as during the period of growth, when more was required by the system. The other is the custom of eating too fast; and this is injurious,—both by preventing sufficient mastication, and thus throwing on the stomach more than its proper duty,—and also by causing an over-supply of food to be ingested, before there is time for the feeling of satisfaction to replace that of hunger (§ 486).

476. Of the Albuminous, Saccharine, and other matters dissolved in the Chyme, there is reason to believe that part are absorbed through the blood-vessels so copiously distributed on the walls of the stomach (§ 492). The remainder, with the undissolved matters, pass into the duodenum, where the chyme is mingled with the *biliary* and *pancreatic* secretions.—The secretion of *Bile* is evidently a process of the highest importance in the economy; as we may judge alike from the size of the Liver and the supply of blood it receives, and from the rapidly-fatal effects of its suspension. That a part of it is purely excrementitious, and is poured into the intestinal tube for the purpose of being carried out of the body, can scarcely be questioned; but there is strong evidence, that a part of it is destined to be absorbed again, after performing some action of importance upon the contents of the alimentary canal.—In all but the very lowest animals, we find traces of a bile-secreting apparatus; and this is almost constantly situated in the immediate neighbourhood of the stomach. In many cases, the secretion is poured directly into the cavity of that organ; but in most, it is conveyed (as in Man) into the intestinal tube near its commencement. Hence it seems clear, from the disposition of the biliary apparatus, that it has a purpose to serve in connection with the digestive function, and is not destined solely for the elaboration of a product which is to be cast-out of the body; since, if the latter were the case, that product would be carried-out immediately, like the urinary excretion, and would not be discharged into the alimentary canal high up.—This conclusion is confirmed by experiment; for it has been shown that if the bile-duct be divided, and be made to discharge its contents externally through a fistulous orifice in the walls of the abdomen, instead of into the intestinal canal, those animals which survive the immediate effects of the operation, exhibit indications of the imperfect performance of the digestive process. At first they eat much, but their food does not seem to impart to them an adequate amount of nutrition; afterwards they lose their appetite, become thin, and usually die after an interval of some months passed in this state. If, however, they be allowed to lick the orifice, so as to receive the fluid discharged from it into their stomachs, these injurious results do not follow.—Observation of disease in the Human subject leads to

similar conclusions; for, when the biliary secretion is deficient, or its flow into the intestine is obstructed, the digestive processes are evidently disordered, the peristaltic action of the bowels is not duly performed, the fæces are white and clayey, and there is an obvious insufficiency in the supply of nutriment prepared for the absorbent vessels.

477. On the other hand, that one great object of the secretion is to withdraw from the Blood certain products of the decomposition of the tissues, which would otherwise accumulate in it, and would be deleterious to its character, is shown by evidence yet more decisive. We find that the action of the Liver is *constant*, and not occasional, like that of the Salivary and Gastric glands; and that, if anything interfere with the secreting process, and thereby cause the accumulation of the elements of the bile in the blood, the effects of their presence are immediately manifested in the disorder of other functions, especially those of the nervous system (§ 399); and the continued suspension of the function leads to a fatal result, unless the elements of the bile are drawn-off (as sometimes happens) by the urinary organs. When the secreting action of the liver has once been performed, however, an obstruction to the discharge of the bile into the intestine does not seem to be so immediately injurious. The fluid accumulates, and distends the bile-ducts and the gall-bladder; and when they are completely filled, part of it is re-absorbed into the blood, apparently in a changed condition, since it does not *then* produce the same injurious effects, as result from the accumulation of its materials previously to the action of the Liver upon them. The colouring-matter seems to be very readily taken-back into the circulating system; and is deposited by it in almost every tissue of the body.

478. Although the secreting action of the Liver is constant, yet the discharge of bile into the intestine is certainly favoured by the presence of chyme in the latter. The purpose of the gall-bladder is obviously to permit the accumulation of bile, when it is not wanted in the intestine; and we find it most constantly present in those tribes of animals which live upon animal food, and which therefore take their aliment at intervals; whilst it is more frequently absent in those herbivorous animals, in which the digestive process is almost constantly going-on. The middle coat of the bile-ducts is clearly muscular, and has a peristaltic action like that of the intestinal canal; this action may be excited by galvanism, or by irritation of the branches of the Sympathetic nerve with which it is supplied. The mucous coat of the ductus choledochus is disposed in valvular folds, in such a manner as to prevent the reflux of the bile or of the contents of the intestine; and a still further security is afforded by the valvular covering to the orifice of the duct, which is furnished by the mucous covering of the intestine itself. The flow of bile into the intestine, when its presence is needed there, is

commonly imputed to the pressure of the distended Duodenum against the gall-bladder; but it is probable that the contractility of the muscular coat of the duct itself, which may be excited either through the sympathetic nerve, or by irritation at the orifice of the duct (as in the case of the Salivary glands), is the real cause of the discharge of the fluid. It is an interesting fact, which proves how much the passage of the Bile into the Intestine is dependent upon the presence of aliment in the latter, that the gall-bladder is almost invariably found turgid in persons who have died of starvation; the secretion having accumulated, through the want of demand for it, although there was no obstacle to its exit.—The quantity of bile daily poured into the intestinal canal, is estimated by Bidder and Schmidt at about 56 ounces, containing about 2½ oz. of solid matter.

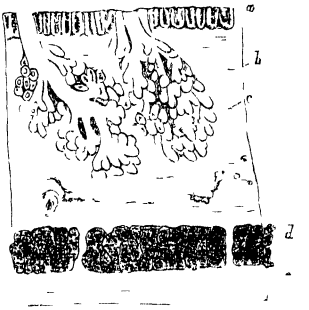
479. The composition of the Bile, and the structure of the organ which elaborates it, will be more appropriately considered hereafter, when the Secreting apparatus generally is being described (CHAP. IX.). At present we have to inquire what is the precise effect of its admixture with the products of digestion, and what is the purpose which this admixture serves.—In the first place, it may be stated that biliary matter is essentially a soap, formed by the union of a fatty acid with a soda-base; and that it serves the purpose of neutralizing the acidity of the chyme, which is derived from the gastric juice. Further, the bile shares with the pancreatic fluid in that emulsifying power, by which the fatty matters of the food are reduced to a state of such fine division as to be rendered capable of being absorbed; and thus it happens that the introduction of these matters into the system, through the medium of the lacteal absorbents (§ 494), does not take-place until after the chyme has been mingled with the biliary and pancreatic secretions. Again, it has been asserted (but the fact has not been fully substantiated), that the admixture of biliary matter produces a conversion of saccharine into fatty compounds.—When fresh bile is mingled with newly-formed chyme, in a glass vessel, the mixture separates into three distinct parts; a reddish-brown sediment at the bottom, a whey-coloured fluid in the centre, and a creamy pellicle at the top. The central stratum probably contains the albuminous, gelatinous, saccharine, and other matters in a state of solution; the superficial pellicle may be looked-upon as consisting chiefly of oleaginous matter destined for absorption; whilst the sediment, partly consisting of the unreducible portion of the food, and partly of the biliary matter itself, is evidently excrementitious.

480. The *Pancreatic* secretion has a chemical constitution very analogous to that of Saliva; but the peculiar organic compound which it contains, has been found by M. Bernard to possess a special power of emulsifying fatty matter, when mingled with it;

and there is strong reason to believe that the chief purpose of this secretion is to effect such a change in the condition of the oleaginous constituents of the chyme, as may prepare them for absorption. But further, the neutralization of the acid of the gastric fluid now allows the metamorphosis of starch to be recommenced; and as there is evidence that the production of sugar continues to take place during the passage of the chymous mass along the small intestines, in animals whose food is partly or completely vegetable, the pancreatic fluid, which has been *experimentally* ascertained to possess this power, is probably the chief agent by which the conversion is effected.

481. Besides the foregoing secretions, there is poured into the upper part of the intestinal canal a fluid secreted in its own walls, which has received the designation of *Succus Entericus*. It seems not improbable that the secretion of this fluid may be the function of the Glands of Brunner; which are small clusters of follicles (Fig. 85), not unlike those of which the salivary glands are composed, lying between the mucous and muscular coats of the duodenum and the commencement of the jejunum. The 'intestinal juice' appears, from the researches of Bidder and Schmidt, to be a colourless viscid liquid, invariably alkaline in its reaction, and containing from 3 to 3½ per cent. of solid matter. The total amount daily secreted by Man is estimated by these experimenters at about 7 oz. Its properties, according to them, are extremely remarkable; for it exerts a solvent action on albuminous bodies hardly inferior to that of the gastric juice, and a power of converting starch into sugar which is scarcely less than that of saliva or pancreatic fluid.

Fig. 85.*



482. The fluid of the Small Intestines, compounded of the salivary, gastric, intestinal, biliary, and pancreatic secretions, appears to possess the very peculiar power of dissolving, or of

* Vertical section of Mucous Membrane of Jejunum, showing Brunner's Glands;—*a*, follicles of Lieberkuhn; *b*, cellular coat of intestine; *c*, Brunner's glands; *d*, annular fibres of muscular coat; *e*, longitudinal fibres of muscular coat.

reducing to an absorbable condition, alimentary substances of every class. This process goes-on during the passage of the contents of the alimentary canal along the Small Intestine; and the nutritious matter, thus progressively prepared for absorption, is gradually withdrawn by the absorbents and blood-vessels of the villi (§§ 492, 494), leaving only the excrementitious residue.—Many of the lower animals are furnished, at the part where the small intestine enters the large, with a *cæcum*, resembling that which in Man is termed the vermiform appendage of the cæcum, but greatly exceeding it in size. Sometimes we find two cæca instead of one; and these are much prolonged, so as to form tubes of considerable length. It has been ascertained that, in herbivorous animals, a distinctly-acid secretion is formed by the cæcum, during the digestive process; and there is reason to believe that the food there undergoes a second process, analogous to that to which it has been submitted in the stomach, and fitted to extract from it any undissolved alimentary matter which it may still contain. There is no reason to believe, however, that any such process takes place in Man, whose real cæcum is rudimentary,—the part of the intestine which has received the name, being merely the dilated commencement of the colon. The act of Defecation, by which the excrementitious matter is discharged, has been already noticed (§ 462); the Absorption of nutritive matter will be treated-of in the succeeding Chapter.

5. *Of Hunger, Satiety, and Thirst.*

483. The want of solid aliment is indicated by the sensation of Hunger; and the deficiency of fluid by that of Thirst. On the other hand, the presence of a sufficiency of food or liquid in the stomach is indicated by the sense of Satiety. These sensations are intended as our guides, in regard to the amount of aliment we take in. What is the real seat of these sensations, and on what conditions do they depend?—The sense of Hunger is referred to the stomach, and seems *immediately* to depend upon a certain condition of that organ; but what that condition is, has not yet been precisely ascertained. It is not produced by mere emptiness of the stomach, as some have supposed; for, if the previous meal have been sufficient, the food passes entirely from the cavity of the stomach, before a renewal of the sensation is felt. It cannot be due to the action of the gastric fluid upon the coats of the stomach themselves; because this fluid is not poured into the stomach, except when the production of it is stimulated by the irritation of the secreting follicles. It has been attributed to distension of the gastric follicles by the secreted fluid; but there is no evidence that the fluid is secreted before it is wanted; and, moreover, as it is well known that mental emotion can dissipate in a moment the keenest appetite, it is difficult to imagine how this can occasion the emptying of the

follicles. Perhaps the most satisfactory view is that which attributes the sense of hunger to a determination of blood to the stomach, preparing it for the secretion of gastric fluid; since this is quite adequate to account for the impression made upon the nerves; and it accords with what has just been stated of the influence of mental emotions, since we know that these have a powerful effect upon the circulation of blood in the minute vessels (§ 603).

484. Although the sense of Hunger is immediately dependent, in great part at least, upon the condition of the stomach, yet it is also indicative of the condition of the general system; being extremely strong when the body has undergone an unusual waste without a due supply of food, even though the stomach be in a state of distension; whilst it is not experienced, if, through the general inactivity of the system, the last supply has not been exhausted, even though the stomach has been long empty. It is well known that, when food is deficient, the attempt to allay the pangs of hunger by filling the stomach with non-nutritious substances, is only temporarily successful; the feeling soon returning with increased violence, though it has received a temporary check. The reason for this is obviously, that the general system has received no satisfaction, although the stomach has been caused to secrete gastric fluid by the contact of solid matter with its walls; so that although the state on which hunger immediately depends has been for a time relieved, this state is soon renewed, unless the solid matter introduced into the stomach be of an alimentary character, and be dissolved and carried into the system.

485. When the food is nutritious in its character, but of small bulk, experience has shown the advantage of mixing it with non-nutritious substances, in order to give it bulk and solidity; for if this be not done, it does not exert its due stimulating influence upon the stomach; the gastric juice is not poured-forth in proper quantity; and the result is, that neither is the sense of hunger relieved, nor are the wants of the body satisfied. Thus the Kamschatdales are in the habit of mixing earth or saw-dust with the train-oil on which alone they are frequently reduced to live. The Veddahs or wild hunters of Ceylon, on the same principle, mingle the pounded fibres of soft and decayed wood with the honey on which they feed when meat is not to be had; and on one of them being asked the reason of the practice, he replied, "I cannot tell you, but I know that the belly must be filled." It has been found that soups and fluid diet are not more readily converted into chyme than solid aliment, and are not alone fit for the support of the body in health; and it is often to be observed, in disordered states of the stomach, that it can retain a small quantity of easily-digested solid food, when a thin broth would be rejected.

486. The sense of Satiety is the opposite of Hunger, and depends, like it, on two sets of conditions,—the state of the stomach, and

that of the general system. It is produced in the first instance by the ingestion of solid matter into the stomach, which gives rise to the feeling of fulness; but this is only a part of the sensation which ought to be experienced; and it is only when the act of digestion is being duly performed, and nutritive matter is being absorbed into the vessels, that the peculiar feeling of satisfaction is excited, which indicates that the wants of the system at large are being supplied. It has been very justly remarked by Dr. Beaumont, that the cessation of the demand set-up by the system, rather than the positive feeling of satiety, should be the guide in regulating the quantity of food taken into the stomach. The sense of satiety is beyond the point of healthful indulgence; and is Nature's earliest indication of an abuse and overburden of her powers to replenish the system. The proper intimation is the pleasurable sensation which is experienced, when the cravings of the appetite are first allayed; since, if the stomach be sufficiently distended with wholesome food for this to be the case, it is next to certain that the digestion of that food will supply what is required for the nutrition of the body. It is only when the substance with which the stomach is distended, is *not* of a digestible character, that the feelings excited by the state of that organ are anything but a correct index of the wants of the system.

487. The Par Vagum is evidently the nerve which conveys to the sensorium the impression of the state of the *stomach*, and which is therefore the immediate excitor of the sensation of hunger or of the feeling of satiety. But it is evident from experiments upon animals, that it is not the only source through which they are incited to take food, and are informed when they have ingested enough; and it is probable that the Sympathetic nerve is the channel through which the wants of the *system* are made known, and through which, in particular, the feeling of general exhaustion is excited, that is experienced when there has been an unusual waste, or when the proper supply has been too long withheld.

488. The conditions of the sense of Thirst are very analogous to those of hunger; that is, it indicates the deficiency of fluid in the body at large; but the immediate seat of the feeling is a part of the alimentary canal,—not the stomach, however, but the fauces. It is relieved by the introduction of fluid into the circulating system, through *any* channel; whilst the mere contact of fluid with the surface to which the sensation is referred, produces only a temporary effect, unless absorption take-place. If liquids be introduced into the stomach by an œsophagus-tube, they are just as effectual in allaying thirst as if they were swallowed in the ordinary manner; and the same result follows the injection of fluid into the veins (as was most remarkably the case when this method of treatment was practised in the Asiatic Cholera), or the absorption of fluid through the skin or the lower part of the alimentary canal. The deficiency

of fluid in the body may arise,—and Thirst may consequently be induced,—either by an unusually-small supply of fluid, or by excessive loss of the fluids of the body, as by perspiration, diarrhea, &c. But it may also be occasioned by the impression made by particular kinds of food or drink upon the alimentary canal; thus salted or highly-spiced meat, fermented liquors when too little diluted, and other similar irritating agents, excite thirst; the purpose of which sensation is evidently to occasion the ingestion of fluid, by which these substances may be diluted, and their irritating action prevented.

CHAPTER V.

ABSORPTION AND SANGUIFICATION.

1. *Absorption from the Digestive Cavity.*

489. So long as the Alimentary matter is contained in the digestive cavity, it is as far from being conducive to the nutrition of the system, as if it were in contact with the external surface. It is only when absorbed into the vessels, and carried by the circulating current into the remote portions of the body, that it really becomes useful in maintaining the vigour of the system, by replacing that which has decayed, and by affording the materials for the various organic processes which are continually going-on. Among the Invertebrated animals, we find the reception of alimentary matter into the circulating current to be entirely accomplished through the medium of the same system of vessels, as that which conveys it through the body at large. We very commonly observe, indeed, that the intestinal tube is completely enclosed within a large venous sinus, so that its whole external surface is bathed with blood; and into this sinus, the alimentary materials would appear to transude, through the walls of the intestinal canal, to become mingled with the blood, and to be conveyed with its current into the remote portions of the body. Among the Vertebrata, we find an additional set of vessels, interposed between the walls of the intestine and the sanguiferous system, for the purpose, as it would seem, of taking-up that portion of the nutritive matter which is not in a state of perfect solution, and of preparing it for being introduced into the current of the blood. These vessels are the *lacteals* or *absorbents*. They are very copiously distributed upon the walls of the small intestine, commencing near the entrance of the biliary and pancreatic ducts; the walls of the large intestine are less abundantly supplied with

them, and they do not show themselves in the villi which are found on some parts of the lining membrane of the stomach, although the walls of that viscus are supplied with *lymphatic* absorbents.

490. Nevertheless it is quite certain that substances may pass into the current of the circulation, which have been prevented from passing further than the stomach; thus, if a solution of Epsom-salts be introduced into the stomach of an animal, and its passage into the intestine be prevented by a ligature around the pylorus, its purgative action will be exerted nearly as soon as if the communication between the stomach and intestines had been left quite free; or if a solution of prussiate of potash be introduced into the stomach under similar circumstances, the presence of that salt in the blood may be speedily demonstrated by chemical tests. It appears from the experiments of MM. Tiedemann and Gmelin, that when various substances were mingled with the food, which, by their colour, odour, or chemical properties might be easily detected,—such as gamboge, madder, rhubarb, camphor, musk, asafœtida, and saline compounds,—they were seldom found in the chyle, though many of them were detected in the blood and in the urine. The colouring matter appeared to be seldom absorbed at all; the odorous substances were generally detected in the venous blood and in the urine, but not in the chyle; whilst, of the saline substances, many were found in the blood and in the urine, and only a very few in the chyle.

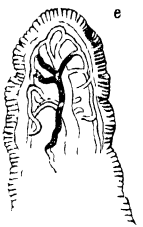
491. This passage of substances in a state of perfect solution, from the stomach into the blood-vessels, is probably due to the operation of that peculiar modification of Capillary Attraction, which is called *Endosmose*. When two fluids differing in density are separated by a thin animal or vegetable membrane, there is a tendency to mutual admixture through the pores of the membrane; but the less dense fluid will transude with much greater facility than the more dense; and consequently there will be a considerable increase on the side of the denser fluid, whilst very little of this in comparison will have passed towards the less dense. When one of the fluids is contained in a sac or cavity, the flow of the other towards it is termed Endosmose, or flow-inwards; whilst the contrary current is termed Exosmose, or flow-outwards. Thus if the cæcum of a fowl, filled with syrup or gum-water, be tied to the end of a tube, and be immersed in pure water, the latter will penetrate the cæcum by Endosmose, and will so increase the volume of its contents, as to cause the fluid to rise to a considerable height in the attached tube. On the other hand, a small proportion of the gum or syrup will find its way into the surrounding fluid by Exosmose. But if the cæcum were filled with water, and were immersed in a solution of gum or sugar, it would soon be nearly emptied, the Exosmose being much stronger than the Endosmose.—It is in this manner that we may cause the flattened corpuscles of the blood to

be distended into spheres, by treating them with water; or may empty them almost completely, by immersing them in syrup (§ 215); since their contents are more dense than the surrounding fluid in the first case, so that they will be augmented by Endosmose; whilst they are less dense in the second, so as to be diminished by Exosmose.

492. Now it seems to be in this manner, that substances contained in the cavity of the stomach, and perfectly dissolved by its fluids, are received into the blood-vessels; for as the blood is the fluid of greater density, it will have a tendency to draw towards itself the saline and other matters which are in a state of perfect solution in the stomach. The Mucous membrane which forms the inner wall of that organ, is most copiously supplied with blood-vessels; partly, indeed, that they may afford the materials of the gastric secretion; but partly, also, that they may take-up the substances which are capable of entering the circulating current by this direct channel. The movement of blood through the vessels tends to accelerate the permeation of liquids through their walls in a very remarkable degree; as may be shown by the following simple experiment:—If a membranous tube, such as a piece of the small intestine or of a large vein of an animal, be fixed by one extremity to an opening at the bottom of a vessel filled with water, and have a stopcock attached at the other extremity, and be then immersed in water acidulated with sulphuric or hydrochloric acid, it will be some time before the acid will penetrate to the interior of the tube which is distended with water; but if the stopcock be opened and the water be allowed to discharge itself, the presence of the acid will be immediately discovered (by tincture of litmus) in the liquid which flows-out. Thus the continuance of the Circulation is obviously one of the most important of the conditions of Absorption. It is whilst passing through the system of capillaries, which forms a minute plexus immediately beneath the free surface of the mucous membrane, that the blood thus receives an admixture of the soluble matters contained within the digestive cavity; and hence it is that these substances are detectible in the blood of the gastric and mesenteric *veins*, sooner than in any part of the arterial system. They are very rapidly diffused, however, through the general circulation; and may even show themselves in the excretions within so short a period, that it is obvious that they must have been absorbed immediately on their introduction into the stomach. Thus Mr. Erichsen found that he was able to detect the presence of ferrocyanide of potassium in the urine, within *one minute* after it had been swallowed in solution. This, however, was only when it was taken after a long fast; more commonly the absorption is less rapid; and if the substance be introduced within an hour or two after a full meal, as much as half an hour may elapse before its presence in the urine gives evidence of its having been received into the circu-

lating current. Although it is difficult to speak with certainty on the point, yet there appears a strong probability, that, both in the stomach and intestinal tube, the absorption of nutritive matters in a state of *perfect solution* (such as gum, sugar, pectin, gelatin, and soluble albumen) is thus accomplished through the medium of the blood-vessels; which also take-up the chief supply of water that is required by the system. It is difficult else to see the purpose of the extraordinary vascularity of the mucous membrane, and in particular of those filaments or narrow folds, termed *villi*, which so thickly cover its surface. Each of these villi is furnished with a plexus of minute blood-vessels (Fig. 86), of which the larger branches may even be seen with the naked eye, when they are distended with blood or with a coloured injection. By these villi, the vascular surface of the mucous membrane is enormously extended. In Man, they are commonly cylindrical or nearly so, and are from about a quarter of a line to a line and a half in length; but in many of the lower animals, they are spread-out into broader laminæ at the base, and are connected-together so as to form ridges or folds.

Fig. 86.*



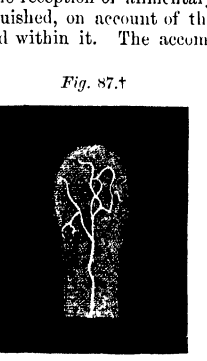
493. The nutritive materials taken-up by the blood-vessels of the alimentary canal, are not conveyed directly into the general circulation; for they are first submitted to the agency of the Liver. All the veins which return the blood from the gastro-intestinal capillaries, converge into the portal trunk, which distributes it to the various portions of that secreting apparatus; and there is strong reason to believe, that not merely is the fluid there *depurated* of some matters whose presence would be injurious, but that the Liver exercises a powerful *assimilating* action upon the proper nutritive substances, rendering them fitter to become components of the Blood. For the blood of the portal vein, when examined during digestion, is found to contain a large proportion of an imperfect albumen, which appears to be the immediate product of the digestive operation; whilst, in that which has passed through the liver, this is found to have given place to the proper albumen of the blood. Further, it appears that *fatty matters* may be elaborated in the liver, either from saccharine substances, or from albuminous compounds; for even when no fat can be detected in the blood of the vena portæ, that of the hepatic vein contains it in considerable amount. So, again, it seems to be well established that the liver

* Intestinal Villus of a Pig, under slight compression, showing its covering of cylinder-epithelium, and its capillary network.

elaborates from some other constituents of the blood a peculiar *saccharine* compound (resembling diabetic sugar), which is destined for immediate elimination by the lungs, and which, being much more readily carried-off by the respiratory process than either grape-sugar or cane-sugar, may be regarded as its most appropriate pabulum.—Further, if white of egg mixed with water be injected into any of the systemic veins, distinct evidence of the presence of albumen is speedily traceable in the urine, showing that this substance has not been properly assimilated: but if the same fluid be injected into the portal system, no trace of its presence in the urine is found. So, again, when a solution of sugar is injected into the general venous system, this substance soon shows itself in the urinary excretion; but if the same injection be made into the vena portæ, so that the sugar is obliged to pass through the liver, no such elimination of it takes-place, as it is then assimilated to the blood. The liver, however, is not required to effect a corresponding change in the fatty matters taken-up from the food; for these are received into the blood through the absorbents, rather than through the sanguiferous vessels; and it is found that if fatty matters be injected into the general circulation, no effect is produced on the urine.*

494. Every one of the intestinal Villi, however, also contains the commencement of a proper *lacteal* vessel; the portion of the absorbent system specially adapted for the reception of alimentary matters from without, being thus distinguished, on account of the milky aspect of the fluid which is found within it. The accompanying figure represents the appearance offered by the incipient lacteals, in a villus of the jejunum of a young man, who had been hung soon after taking a full meal of farinaceous food. The trunk that issues from the villus is formed by the confluence of several smaller branches, whose origin it is difficult to trace; but it is probable that they form loops by anastomosis with each other, so that there is no proper free extremity in any case. It is quite certain that the lacteals never open by free orifices upon the surface of the intestine, as was formerly imagined. And there seems good reason to believe, that by the epithelial cells which cover the extremities of the villi (§ 243), a *selection* is made of those sub-

Fig. 87.†



* See the Lectures and Memoirs of M. Cl. Bernard, in "L'Union Médicale," and the "Gazette Médicale," for 1850.

† One of the Intestinal Villi, with the commencement of a lacteal.

stances which are proper to be received into the special Absorbent system.

495. It is particularly important to keep in view the difference between the two modes by which alimentary substances are introduced into the system, when we are treating those disordered states in which the digestive process is imperfectly performed, or is altogether suspended. There can be little doubt that the *immediate* cause of death, in many diseases of exhaustion, is the want of power to maintain the heat of the body; the stomach not being able to digest food, and the special absorbing power of the lacteals being entirely suspended, so that the inanition is as complete as if food were altogether withheld. Now under such circumstances it becomes a matter of the greatest importance to present a supply of combustible matter, in such a form that it may be introduced into the circulating system by simple Endosmose; and the value which experience has assigned to broths and to *thin* farinaceous solutions, and still more, to diluted alcoholic drinks, frequently repeated, under such circumstances, seems to depend in great part upon the facility with which they may be thus absorbed. The good effects of alcohol, cautiously administered, are no doubt owing in part to its specific influence upon the nervous system; but that they are also due to its heat-producing power, appears from the results of the administration of frequently-repeated doses in states of utter exhaustion,—the temperature of the body being kept-up so long as they are continued, and falling when they are intermitted (§ 118). As the alcohol is thus burned-off nearly as fast as it is introduced, it never accumulates in sufficient quantity to produce its usual violently-stimulating effects upon the nervous system.

2. *Passage of the Chyle along the Lacteals, and its admixture with the Lymph collected from the general System.*

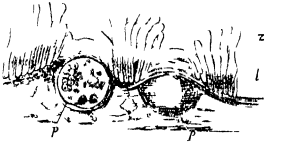
496. The Lacteal vessels, which commence on the surface of the intestines, run-together on their walls, and form larger trunks, which converge and unite with each other in the mesentery. They are connected, very near their origin, with the peculiar bodies which are termed 'Peyer's glands:' these may be either 'solitary' or 'agminated;' the former presenting themselves along nearly the whole length of the intestinal canal, whilst the latter are restricted to the small intestine, being most abundant at the lower part of the ileum. Each 'Peyerian body,' in a healthy mucous membrane, presents the appearance of a circular, white, slightly-raised spot, about a line in diameter, over which the membrane is usually less beset with villi, and is very often entirely destitute of them; and it is surrounded by a ring of openings, which are the orifices of a set of cæcal follicles disposed in a zone around it (Fig. 88). The wall

of this body is not (as was formerly supposed) a proper membrane like that of a gland-vesicle, but is composed of distinctly-fibrillated connective tissue, with interspersed nuclei; the substance which it encloses is a granular pulp, containing fatty and albuminous molecules of various sizes, with nuclear particles and a few cells (Fig. 89); and thus the entire corpuscle is far from being completely differentiated from the tissues in which the gland is imbedded. Each is surrounded by a close vascular network, from which capillary vessels pass into the midst of its contents, returning thence by loops which re-enter the plexus.—The same general type of structure prevails in the 'Mesenteric glands,' which the lacteals enter in their passage across the mesentery. Each of these consists of a sheath or capsule of fibrous tissue, which sends inwards a large number of thin lamellæ, so disposed and connected-together as to constitute a tolerably-regular framework pervading the entire corpuscle and subdividing its internal substance into a number of rounded chambers or 'alveoli.' These are filled with a greyish-white pulp, which agrees in all its characters with that of the Peyerian bodies, and which is penetrated, like it, by a fine capillary plexus; and they are so connected with the incurrent and the excurrent lacteals, that the fluid brought to the glands by the former must traverse their pulp before finding its way into the latter. Both the Peyerian and the Mesenteric glands may be considered in the light of dilatations of the Lacteal absorbents, with a largely-increased development both of the fibrous tissues which bound them, and of the cellular elements which they contain; and

Fig. 88.*



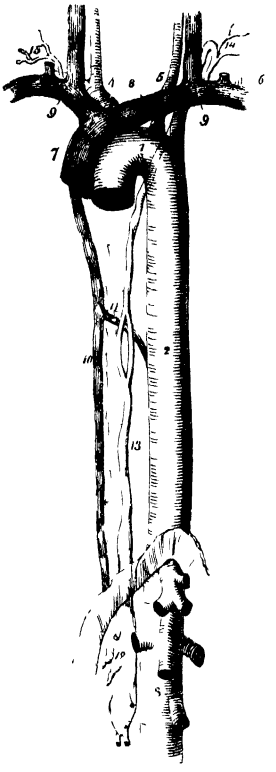
Fig 89 †



* Surface-aspect of a portion of the Intestinal Mucous Membrane, showing the isolated Peyerian follicles, *f*, *f*, and the villi.

† Vertical section of the Intestinal Mucous Membrane, bringing into view two Peyerian follicles:—*z*, villi; *l*, follicles of Lieberkühn; *m*, muscular coat; *c*, cellular coat; *p*, *p*, Peyerian capsules, one of them shown in section, the other not cut-open.

Fig. 90.*



their influence upon the fluid that traverses them may fairly be supposed to be a more concentrated form of that which is diffused in a feebler degree through the entire Absorbent system. The whole apparatus may be regarded with much probability as a great Assimilating Gland, the component parts of which are scattered, instead of being concentrated into one mass.

497. After emerging from the mesenteric glands, the lacteal trunks converge, with occasional union, until they discharge their contents into the *receptaculum chyli*, which is situated at the front of the body of the second lumbar vertebra (Fig. 90, 12). Into the same cavity are poured the contents of a part of the other division of the Absorbent system which is distributed through the body in general, and which, from the transparency of the fluid or lymph it contains, is termed the *lymphatic* system. From the receptaculum chyli arises the *thoracic duct* (13); which passes upwards in front of the spine, receiving other lymphatic trunks in its course, to terminate at the junction of the left subclavian and jugular veins; where it delivers its contents into the sanguiferous system (14). A smaller duct (15) receives some of the lymphatics of the right side, and

* The course and termination of the Thoracic Duct.—1. the arch of the aorta; 2. the thoracic aorta; 3. the abdominal aorta, showing its principal branches divided near their origin; 4. the arteria innominata, dividing into the right carotid and right subclavian arteries; 5. the left carotid; 6. the left subclavian; 7. the superior cava, formed by the union of, 8, the two venæ innominatæ; and these by the junction, 9, of the internal jugular and subclavian vein at each side; 10. the greater vena azygos; 11. the termination of the lesser in the greater vena azygos; 12. the receptaculum chyli; several lymphatic trunks are now seen opening into it; 13. the thoracic duct, dividing

there terminates at a corresponding part of the venous system; but it does not receive any of the contents of the lacteals.

498. The Lymphatic system is evidently allied very closely to the lacteal, in its general purposes; and makes its first appearance in the same class of animals, namely in Fishes. The vessels of which it is composed are distributed through most of the softer tissues of the body, and are particularly abundant in the skin. They have never been found to commence by closed or open extremities; but seem to form a network, from which the trunks arise. In their course they pass through glandulæ disposed in different parts of the body, which exactly resemble in structure those which are found upon the lacteals in the mesentery. And they at last terminate, as already shown, in the same general receptacle with the lacteals. Hence it cannot be reasonably doubted that the fluid which they absorb from the various tissues of the body, is destined to become again subservient to nutrition; being poured-back into the current of the blood, along with the new materials which are now for the first time being introduced into it. That the special Absorbent apparatus of Vertebrated animals has for part of its function to effect a change in the materials absorbed, and thus to aid in fitting them for introduction into the blood, seems apparent from the facts of Comparative Anatomy; which show that the more distinct the blood is from the chyle and lymph, the more marked is the provision for delaying the latter in the absorbent system, and for subjecting it to preliminary change.

499. The course of the Absorbent vessels in *Fishes* is short and simple; they are not furnished with glands; and they pour their contents into the blood-vessels at several different parts of the body. In this class the blood contains fewer red corpuscles, and its coagulating power is feebler, than in any other Vertebrata. And in the lowest tribes, in which the Vertebrated character is almost entirely wanting, and in which the blood is almost pale, no special absorbent system has yet been discovered.—In *Reptiles*, the length of the Absorbent vessels is remarkably increased by their doublings and convolutions; so that the system appears to be more highly developed than in either of the warm-blooded classes. But this superiority is not real; for there is yet no trace of the glands, which concentrate, as it were, the assimilative power of a long series of vessels. Moreover, we often find the lymphatics of this class furnished with pulsating dilatations, or *lymphatic hearts;*

opposite the middle of the dorsal vertebræ into two branches, which soon reunite; the course of the duct behind the arch of the aorta and left subclavian artery is shown by a dotted line; 14. the duct making its turn at the root of the neck, and receiving several lymphatic trunks previously to terminating in the posterior aspect of the junction of the internal jugular and subclavian vein; 15. the termination of the trunk of the ductus lymphaticus dexter.

which have for their office to propel the lymph into the venous system. In the Frog there are two pairs of these, one situated just beneath the skin (through which its pulsations are readily seen in the living animal) immediately behind the hip-joint, the other pair being more deeply seated at the upper part of the chest. The former receive the lymph of the posterior part of the body, and pour it into the veins proceeding from the same part; the latter collect that which is transmitted from the anterior part of the body and head, and empty their contents into the jugular vein. Their pulsations are totally independent of the action of the heart and of the respiratory movements; since they continue after the removal of the former, and for an hour or two subsequently to the death and complete dismemberment of the animal. They usually take-place at the rate of about sixty in the minute; but they are by no means regular, and are not synchronous on the two sides.

500. In *Birds*, we find the Absorbent system existing in a more perfect form; its diffused plexuses and convolutions being replaced by glands, in which the contained fluid is brought into closer proximity with the blood, and in which it is subjected to the influence of assimilating cells. These, however, are not very numerous; being principally found on the lymphatics of the upper extremities. The absorbents, in this class, terminate principally by two thoracic ducts, one on each side, which enter the jugular veins by several orifices. There are, however, two other entrances, as in Reptiles, into the veins of the lower extremity; and these are connected with two large dilatations of the lymphatics, which are evidently analogous to the lymphatic hearts of Reptiles, but which have little or no power of spontaneous contraction.—It is in *Mammalia* that the Absorbent system presents itself in its most developed and concentrated state. The vessels possess firmer walls, and are more copiously provided with valves, than in the classes beneath; and the glands are much more numerous, particularly upon the vessels that receive or imbibe substances from without,—as those of the digestive cavity, the skin, and the lungs. The terminations of the absorbents in the veins are usually restricted, as in Man, to the single point of entrance of the thoracic duct on either side; but they are sometimes more numerous; and certain variations in the arrangement of the thoracic ducts, which occasionally present themselves as irregularities in Man, are the ordinary conditions of these parts in some of the lower Mammalia.

501. With regard to the source of the matters absorbed by the Lymphatics, it is difficult to speak with certainty. We shall presently see that their contents bear a close resemblance to the fluid element of the blood, or 'liquor sanguinis,' in a state of dilution; and it is very probable that they partly consist of the residual fluid, which, having escaped from the blood-vessels into the tissues, and having furnished the latter with the materials of their nutrition,

is now to be returned to the former. But they may include, also, those particles of the solid framework which have lost their vital powers, and which are therefore not fit to be retained as components of the living system, but which have not undergone a degree of decay that prevents them from serving, like matter derived from the dead bodies of *other* animals, as a material for reconstruction, when it has been again subjected to the organizing process.

502. It was formerly supposed (and the doctrine was particularly inculcated by the celebrated John Hunter) that the office of the Lymphatic system is to take-up and remove all the effete matter that is to be cast out of the body, being no longer fit for its nutrition. But for such a supposition there is no adequate foundation. It seems absurd to imagine that this effete matter would be mingled with the newly-ingested aliment, and would be poured-back with it into the general current of the circulation, instead of being at once carried out of the system. And the idea is directly negatived, as we shall presently see, by the actual composition of the lymph drawn from these vessels; the solid matter of which consists, in great part at least, of substances of a nutritive character. It is true that other substances are occasionally found in the lymphatics: thus, when the gall-bladder and bile-ducts are over-distended with bile, in consequence of some obstruction to its exit, the lymphatics of the liver are found to contain a biliary fluid; and in like manner, the lymphatics in the neighbourhood of a large abscess have been found to contain pus. When the limb of an animal, round the upper part of which a bandage is tied, has been kept for some hours in tepid milk, the lymphatics of the skin are found distended with that fluid. And when saline solutions are applied to the skin, they are usually detected more readily in the lymphatics than in the veins. But these facts only prove, that the lymphatics very readily imbibe soluble substances with which they are in proximity; and this imbibition seems to take-place on the same physical principles, as the imbibition of soluble substances by the veins of the intestinal canal.

503. The more ready absorption of such substances by the lymphatics than by the veins of the cutaneous surfaces,—contrary to what obtains in the alimentary canal,—is easily accounted-for by the very abundant distribution of the lymphatics in the skin, and the ready access which fluids can obtain to their walls. In other tissues it is different; thus it appears that saline matters injected into the lungs are detected much sooner in the serum of the blood than they are in the lymph; and make their appearance earlier in the left cavities of the heart, to which they would be conveyed by the pulmonary vein, than in the right, which they would reach through the thoracic duct and descending cava. This is obviously due to the minute distribution of the blood-vessels upon

the walls of the air-cells; which makes them far more ready channels for the imbibition of fluid than the lymphatics could be.—In regard to the occasional absorption of pus from the cavity of an abscess or of an open ulcer, by the lymphatics, it is to be remarked that the absorbent vessels must themselves probably be laid-open by ulceration; since in no other way can we understand the entrance of globules so large as those of pus into their interior.

504. In regard to the cause of the movement of the chyle and lymph along the absorbent vessels, from their commencement to their termination in the central receptacle, no very definite account can be given. The middle coat of these vessels has a fibrous texture; and the fibres bear some resemblance to that of the non-striated muscle. In the thoracic duct, this fibrous structure is more evident; and distinct contractions have been excited in it, by irritating the sympathetic trunks from which it receives its nerves, and the roots of the spinal nerves with which those trunks are connected. Hence it seems probable, that there is a sort of peristaltic contraction of the walls of the absorbents, analogous to that which takes-place in the intestinal tube, serving to drive their contents slowly onwards; any reflux being prevented by the valves with which they are copiously furnished. Moreover, it is probable that the general movements of the body may concur with the contractile power of the absorbent vessels themselves, to urge their contents onwards; for almost every change in position must occasion increased pressure on some portion of them, which will propel the fluid contents in the sole direction permitted by the valves, and thus give them an additional impulse towards the trunks, in which they are collected for delivery into the blood-vessels.

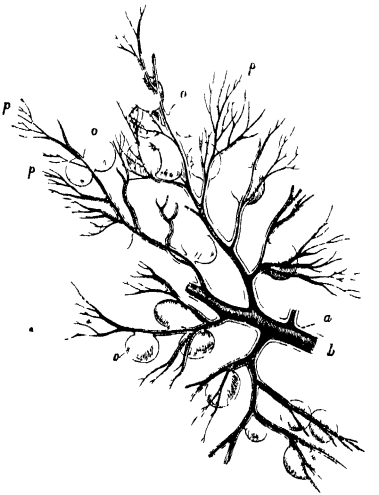
3. *Of the Spleen, and other Glandular Appendages to the Lymphatic System.*

505. The structure and functions of the Spleen, and of certain other organs allied to it in character, have been among the most obscure subjects in Anatomy and Physiology; and they are far from having been yet fully elucidated. There seems sufficient evidence, however, for regarding them in the light of appendages to the Absorbent system, and as concerned, like it, in the process of Sanguification, or the preparation of Blood. Hence this appears to be the most appropriate place for such a brief notice of them as the present state of our knowledge admits.

506. The *Spleen* is certainly to be regarded as an organ of compound structure, having at least two sets of functions to fulfil. It is essentially composed of a fibrous membrane, which constitutes its exterior envelope, and which sends prolongations in all directions across its interior, so as to divide it into a number of minute cavities of irregular form, freely communicating with each other. In

many animals, this fibrous envelope, and the prolongations or *trabeculæ* which it sends through the substance of the organ, are distinctly muscular; containing a large proportion of the peculiar fusiform contractile cells formerly described (§ 337). These, however, do not present themselves in the Human spleen; and its trabeculæ do not appear to have any contractile property. The areolæ formed by the trabecular tissue, commonly known as the *splenic follicles*, are differently occupied in different animals. In the Ruminants they are lined by a continuation of the splenic vein, which dilates into a cavernous structure, capable of receiving a very large quantity of blood. In Man, however, they have no communication with the splenic vein, and are chiefly occupied by the Malpighian corpuscles and the parenchymatous tissue, which, in the Ruminants, are limited to the partitions between the venous cells. The Malpighian corpuscles of the spleen are whitish spherical bodies, which are always connected with the smaller arteries, like currants with their stalks (Fig. 91, *o*, *o*); being sometimes in

Fig. 91.*



* Branch of the Splenic Artery with Malpighian Corpuscles attached;—*a*, sheath of artery; *b*, arterial branch; *p*, *p*, its penicillate subdivisions; *o*, *o*, Malpighian bodies,

immediate contact with them, but more commonly being connected by a peduncle. Their size, when fully formed, varies from 1-3rd to 1-6th of a line. Each of them contains, as its constant and essential elements, nucleated cells from 1-4000th to 1-2500th of an inch in diameter, pale and faintly granular, together with free nuclei, as well as larger cells of 1-2000th of an inch in diameter, which sometimes contain what appear to be red blood-corpuscles. These are enclosed in a capsule which has no orifice, and which is precisely comparable to that of the Peyerian bodies (§ 496); and they are traversed by capillary blood-vessels after the same manner. The number and size of these bodies bear a remarkable relation to the general state of nutrition; being much the greatest in healthy well-fed animals, whilst in those that have been ill-fed they diminish extremely, and may even disappear altogether. The true *splenic parenchyma* consists in great part of cells which correspond in appearance with those of the Malpighian corpuscles; but in addition to these, there are cells which bear a strong likeness to the colourless 'granule-cells' of the blood (§ 217), and others which resemble shrunken red-corpuscles. These elements present indications of being in a state of continual development and degeneration; and form small irregular groups of various sizes, which are clustered especially on the sheaths of the vessels, the trabecular partitions, and the exterior of the Malpighian capsules.—A considerable part of the contents of the splenic areolæ is considered by Prof. Kolliker to consist of blood-corpuscles in various stages of degenerative metamorphosis; and this view has been confirmed by the more recent inquiries of Mr. H. Gray, who affirms that the splenic blood in its passage from the arteries into the veins, normally escapes from the walled vessels into indefinite channels, so that its corpuscles may become diffused through the parenchyma, without any departure from their regular course. The amount of *colourless* spleen-pulp varies, like that contained within the Malpighian corpuscles, in accordance with the general state of nutrition, and especially with the amount of albuminous matters in the blood; whilst the quantity of *red* spleen-pulp is proportional to that of red corpuscles which the blood may contain, being greatly augmented whenever there is a state of plethora, whilst it disappears altogether when the blood is at all poorer in red corpuscles than usual.

507. In regard to the functions of the Spleen, great uncertainty still exists. It appears from the foregoing account of its structure, that it may be regarded as an organ of duplex character, and probably of double function. In the Ruminants, the cavernous dilatations of the veins enable it to hold, upon occasion, a large quantity of blood; and their walls are so elastic, that their cavities may be greatly distended with a very moderate force; the Spleen of the sheep, which weighs about 4 oz., being easily made to contain about 30 oz. of water. This peculiar distensibility evidently points

to the Spleen as a kind of reservoir, connected with the Portal circulation, for the purpose of relieving the portal vessels from undue pressure or distension, under a great variety of circumstances. The portal system is in most animals destitute of valves, so that the splenic vein communicates freely with the whole of it; and thus, if any obstruction exist to the flow of blood through the liver, or any peculiar pressure elsewhere should prevent the mesenteric veins from dilating to their full extent, the general circulation is not disturbed, the Spleen affording a kind of safety-valve. That any cause of congestion of the Portal system peculiarly affects the Spleen, has been proved by experiment; for, after the portal vein has been tied, the spleen of an animal that previously weighed only 2 oz., has been found to increase to 20 oz.—Again, the Spleen appears to serve as a reservoir, into which superfluous blood may be carried during the digestive process. When the alimentary canal is distended with food, and a great afflux of arterial blood takes place to the mucous membrane, the veins of the portal system will be liable to increased pressure from without, whilst their contents will be augmented by the quantity of fluid newly absorbed from the alimentary canal. In this, as in the preceding cases, the distensibility of the spleen makes it a kind of safety-valve, by which undue distension of the portal system is relieved. It has been ascertained that its maximum volume is attained about five hours after a meal, when the process of chymification is at an end, and that of absorption is taking-place with activity; and the increase is proportional rather to the amount of the fluids ingested, than to that of the solids.—Although the Human Spleen has no true cavernous structure, yet its veins are obviously very distensible, so that a great accumulation of blood may take-place in it. Thus, in Asphyxia, when the circulation of blood is checked in the Lungs, and when the stagnation extends itself backwards to the right side of the heart, to the vena cava, and thence to the portal system, the Spleen is often found after death to be enormously distended with blood. And in the cold stage of intermittent fever, in which a great quantity of blood is driven from the surface towards the internal organs, the Spleen receives a large portion of it, so that its increased size becomes quite perceptible; and in cases of confirmed Ague, the Spleen becomes permanently enlarged, forming what is popularly known as the 'ague-cake.'

508. But besides this safety-valve function, there can be little question that the Spleen performs some other, which is related more closely to the nutritive operations, and which in some degree corresponds with that performed by the Absorbent glandulæ. The multitude of glandular cells in immediate relation with blood-vessels, and the appearances of rapid development and degeneration which these present, taken in connection with the fact that there is no other outlet for the products of their action than that which is

afforded by the veins, clearly indicate that whatever this product may be, it is destined to form part of the blood; and that the Spleen is, therefore, an organ of sanguification. This view is confirmed by the remarkable fact, ascertained by recent experiments, that after the spleen has been extirpated, the lymphatic glands of the neighbourhood increase in size, and cluster-together as they enlarge, so as to form an organ which at least equals the original spleen in volume. This circumstance explains the reason of the almost invariable *negative* result of the extirpation of the spleen; for although the operation has been frequently practised, with the view of determining the functions of the organ by the symptoms presented by the animals after its removal, no decided change in the ordinary course of their vital phenomena has ever been observed, and the health, if at all disturbed for a time, is afterwards completely regained. Now if the principal function of the Spleen be the same with that of the lymphatic glands in general, it is easy to understand how its loss may be at once compensated by an increased action on their part, and how it may be permanently replaced by an increased development of certain of those bodies.—It is worthy of remark, that a Spleen is found in *all* Vertebrated animals which have a distinct Absorbent system; but that no organ exactly corresponding with it exists in the Invertebrata, which are destitute of that system,—although the distensible cellated cavities, apparently destined to perform its safety-valve function, exist in some of the higher among them. This is an additional reason for regarding its parenchymatous portion as essentially a part of the assimilating apparatus of the Absorbent system.

509. It would further seem as if the Spleen were specially concerned in the development of the red corpuscles of the blood; since its parenchyma contains cells which resemble these in various stages of development, and similar cells are found, sometimes in considerable abundance, in the blood of the splenic vein. But this organ also appears, under certain circumstances, to promote the disintegration of the red corpuscles; and this so powerfully, that the blood of the splenic vein contains a far *less* proportion of red corpuscles, as well as a far *greater* proportion of albumen, than that of any other vessels in the body. This happens when the red corpuscles are in excess; and hence it seems as if the organ were destined to exert a regulative action upon their amount; supplying them when they are deficient, and getting rid of them when they are over-abundant.

510. The *Supra-Renal Capsules* seem to correspond with the Spleen in their essential structure, whilst in the arrangement of their component parts they bear more resemblance to the Kidney. Their exterior or cortical portion, in Man and the Mammalia generally, is formed of straight arteries, which divide into a minute capillary network; and from this arise venous branches, which form

a minute plexus through the internal or medullary substance, pouring its contents into a large central cavity, which is the dilated commencement of the supra-renal vein. In the lower Vertebrata, however, there is no distinction of cortical and medullary substance; the distribution of vessels being nearly the same throughout. As in the Spleen, we find in the interspaces of the vascular plexus a parenchymatous structure, composed of free cells and nuclei in various stages of development, which lie in elongated spaces bounded by partitions of fibrous tissue, between its parallel blood-vessels. The fluid contents of these bodies are rich in protein-compounds and in fat: and it can be scarcely doubted that these materials here undergo an elaboration, which renders them better fitted for the nutrition of the system. It does not seem unlikely, that these bodies, like the Spleen, have a double function; and that, besides participating in the general actions of the Absorbent glandulæ, they may serve as a diverticulum for the renal circulation, when from any cause the secreting function of the Kidneys is retarded or checked, and the movement of blood through them is stagnated.—The Supra-Renal capsules of Man attain a very large size early in fœtal life, surpassing the true Kidneys in dimension up to the tenth or twelfth week; but they afterwards diminish relatively to the latter, and are evidently subordinate organs during the whole remainder of life. In most of the lower animals, however, these bodies retain through life the same relative development.

511. The *Thymus Gland* is another body which seems referable to the same group; having the essential characters of a true gland (§ 714), save an excretory duct; and its function being evidently connected, during the early period of life at least, with the elaboration of nutritive matter, which is to be re-introduced into the circulating current. Its elementary structure may be best understood from the simple form it presents, when it is first capable of being distinguished in the embryo. It then consists of a single tube, closed at *both* ends, and filled with granular matter; and its subsequent development consists in the lateral growth of branching off-shoots from this central tubular axis. In its mature state, therefore, it consists of an assemblage of hollow glandular lobules, united by connective tissue, and surrounded by a plexus of blood vessels; and their cavities all communicate with the central reservoir, from which, however, there is no outlet. Each lobule is bounded by an indistinctly-fibrous or almost homogeneous membrane, which is lined by a greyish-white pulp, that consists of free nuclei and minute cells, and is traversed by a minutely-distributed capillary plexus, and it thus corresponds in every particular, save the presence of a central cavity, with a Peyerian or Malpighian corpuscle. Cells and nuclei resembling those of the parenchyma, are found in the cavity of the lobule; from which, indeed, the parenchyma is not separated by any distinct limitary membrane. The

chemical composition of this pulpy substance closely corresponds with that of the ordinary protein-compounds.—The Thymus has been commonly said to attain its greatest development, in relation to the rest of the body, during the latter part of fœtal life; and it has been considered as an organ peculiarly connected with the embryonic condition. But this is a mistake; for the greatest activity in the growth of this organ manifests itself, in the Human infant, soon after birth; and it is then, too, that its functional energy seems the greatest. This rapid state of growth, however, soon subsides into one of less activity, which merely serves to keep-up its proportion to the rest of the body; and its increase usually ceases altogether at the age of about two years. From that time, during a variable number of years, it remains stationary in point of size; but if the individual be adequately nourished, it gradually assumes the character of a mass of fat, by the development of the corpuscles of its interior into fat-cells, which secrete adipose matter from the blood. This change in its function is most remarkable in hybernating Mammals; in which the development of the organ continues, even in an increasing ratio, until the animal reaches adult age, when it includes a large quantity of fatty matter. The same is the case, generally speaking, among Reptiles.

512. Various facts lead to the conclusion, that the function of the Thymus, at the period of its highest development, is that of elaborating and storing-up nutritive materials, to supply the demand which is peculiarly active during the early period of extra-uterine life. The elaborating action probably corresponds with that which is exerted by the glands of the Absorbent system; and the product, as in the preceding cases, seems to be taken-back into the circulation. The provision of a store of nutritive matter seems a most valuable one, under the circumstances in which it is met-with; the waste being more rapid and variable than in adults, and the supply not constant. Thus it has been noticed that, in over-driven lambs, the thymus soon shrinks remarkably; but that it becomes as quickly distended again during rest and plentiful nourishment. As the demand becomes less energetic, and as the supplies furnished by other organs become more adequate to meet it, the Thymus diminishes in size, and no longer performs the same function. It then obviously serves to provide a store of material, not for the nutrition of the body, but for the respiratory process, when this has to be carried-on for long periods (as in hybernating Mammals, and in Reptiles,) without a fresh supply of food.—It is possible that the Thymus gland may further stand in the same relation to the Lungs, as the Spleen to the Liver, and the Supra-Renal capsules to the Kidneys; that is, as a *diverticulum* for the blood transmitted through the bronchial arteries (which are the nutritive vessels of the Lungs), before the Lungs acquire their full development in comparison with other organs, or when

any cause subsequently obstructs the circulation through their capillaries.

513. The *Thyroid* Gland bears a general analogy to the Thymus; but its vesicles are distinct from each other, and do not communicate with any common reservoir. They are surrounded, like the vesicles of the true glands, with a minute capillary plexus; and in the fluid they contain, numerous corpuscles are found suspended, which appear to be cell-nuclei in a state of more or less advanced development. This body is supplied with arteries of considerable size, and with peculiarly large lymphatics. Though proportionably larger in the fœtus than in the adult, it remains of considerable size during the whole of life.—It appears from the inquiries of Mr. Simon,* that a Thyroid gland, or some organ representing it in place and office, exists in all Vertebrated animals. It presents its simplest form in the class of Fishes; in some of which it appears to consist merely of a plexus of capillary vessels, connected with the origin of the cerebral vessels, and capable, by its distensibility, of relieving the latter, in case of any obstruction to the proper movement of blood through them. In the higher forms of this organ, the glandular structure,—consisting of the closed vesicles over which the capillary plexus is distributed, and of their cellular contents,—is superadded: and the organ then appears, like the Spleen, to be destined for two different uses; namely, to serve as a *diverticulum* to the Cerebral circulation, and to aid in the elaboration of nutritive matter, which is probably taken-up by the Absorbent system, to be again poured by it into the general current of the circulation.

514. Thus the Spleen, the Supra-Renal Capsules, the Thymus Gland, and the Thyroid Gland, all seem to share in the preparation of the nutritive materials of the blood; in fact, we may regard them all as together constituting an elaborating apparatus, which is essentially analogous to that of the ordinary glands, but of which the elementary parts are scattered through the body instead of being collected into one compact structure, and of which the product is received-back into the blood, instead of being discharged through an efferent duct upon the surface of the body, or into an open cavity. The probable uses of these bodies, as diverticula to the circulation through other organs, render them liable to occasional distension with blood; and it seems determined that this blood shall not lie useless, but shall be subservient to the action in question; the gland-cells that form the parenchyma of the organs withdrawing certain constituents of the blood, to restore them to the circulating current in a state of more complete preparation for the operations of Nutrition. Their function is very probably *vicarious;* that is, the determination of blood is greatest (through the state of

* Philosophical Transactions, 1844.

the other organs) at one time to one of these bodies, and at another time to another. Hence the effects of the loss of any one of them are not serious; as the others are enabled in great degree to discharge its duty.

4. *Composition and Properties of the Chyle and Lymph.*

515. The chief chemical difference between the Chyle and the Lymph, consists in the much smaller proportion of solid matter in the latter, and in the almost entire absence of fat, which is an important constituent of the former. The Lymph obtained from the neck of a horse having been analysed by Nasse, he found it to contain 95 per cent. of water; and the 5 per cent. of solid matter was chiefly composed of albumen and fibrin, with watery extractive,—scarcely a trace of fat being discoverable. The proportions of saline matter were found to be remarkably coincident with those which exist in the serum of the blood, as might be expected from the fact, that the fluid portion of the lymph must have its origin in that which has transuded through the blood-vessels; the absolute quantity, however, is rather less. A similar analysis of the Chyle of a cat by Nasse, gave the following result:—the proportion of water was 90·5 per cent.; and of the 9·5 parts of solid matter, the albumen, fibrin, and extractive amounted to more than 5, and the fat to more than 3 parts. This difference is also well shown in the following comparative analyses, performed by Dr. G. O. Rees, of the fluids obtained from the lacteal and lymphatic vessels of a donkey, previously to their entrance into the thoracic duct; the animal having had a full meal seven hours before its death.

	Chyle.	*Lymph.*
Water	90·237	96·536
Albuminous matter (coagulable by heat)	3·516	1·200
Fibrinous matter (spontaneously coagulable)	0·370	0·120
Animal extractive matter, soluble in water and alcohol	0·332	0·240
Animal extractive matter, soluble in water only	1·233	1·319
Fatty matter	3·601	a trace.
Salts;—Alkaline chloride, sulphate, and carbonate, with traces of alkaline phosphate, oxide of iron	0·711	0·585
	100·000	100·000

Dr. Rees has also analysed the fluid of the Thoracic duct of Man, which consists of chyle with an admixture of lymph; and he found this to contain about 90·5 per cent. of water, 7 parts of albumen

and fibrin, 1 part of aqueous alcoholic extractive, and not quite 1 part of fatty matter, with about ½ per cent. of salines. The composition of this fluid more resembles that of the lymph than that of the chyle; the proportion of the fatty to the albuminous matter being small. This was probably due to the circumstance, that the subject from which it was obtained (an executed criminal) had eaten but little for some hours before his death.

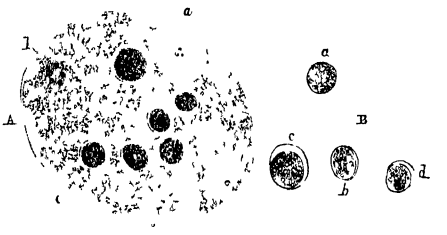
516. The characters of the Chyle are not the same in every part of the Lacteal system; for the fluid undergoes a very important series of changes during its transit from the walls of the intestines to the receptaculum chyli. The fluid drawn from the lacteals that traverse the intestinal walls, has no power of spontaneous coagulation; whence we may infer that it contains little or no Fibrin. It contains Albumen in a state of complete solution, as we may ascertain by the influence of heat or of acids in producing coagulation. And it includes a quantity of Fatty matter, which is not dissolved, but suspended in the form of globules of variable size. The quantity of this evidently varies with the character of the food; it is more abundant, for instance, in the chyle of Man and the Carnivora, than in that of the Herbivora. It is generally supposed that the milky colour of the chyle is owing to the oil-globules; but Mr. Gulliver has pointed-out that it is really due to an immense multitude of far more minute particles, which he has described under the name of the *molecular base* of the chyle. These molecules are most abundant in rich, milky, opaque chyle; whilst in poorer chyle, which is semi-transparent, the particles float separately, and often exhibit the vivid motions common to the most minute molecules of various substances. Such is their minuteness, that, even with the best instruments, it is impossible to determine either their form or their dimensions with exactness; they seem, however, to be generally spherical; and their diameter may be estimated at between 1-36,000th and 1-24,000th of an inch. Though remarkable for their unchangeableness, when submitted to the action of numerous re-agents which quickly affect the proper Chyle-corpuscles, their ready solubility in ether would seem to indicate that they are of an oily or fatty nature; and it is probable that each draws a coating of albuminous matter from the surrounding liquid, whereby their mutual coalescence is prevented.

517. The milky aspect which the serum of blood sometimes exhibits, is due to an admixture of this 'molecular base.' It may be particularly noticed, when blood is drawn a few hours after a full meal that has been preceded by a long fast. By experiments of this kind, it has been found that the serum begins to show this turbidity about half an hour after the meal has been taken; and that the turbidity increases for some hours subsequently, after which it disappears. The period at which the discolouration is greatest, and the length of time during which it continues, vary according to

the digestibility of the food. When the serum is allowed to remain at rest, the opaque matter rises to the surface, presenting very much the appearance of cream; and when separately examined, it has been found to contain a protein-compound, mingled with oily matter,—the relative amount of the two appearing to depend in part upon the characters of the food ingested. The gradual disappearance of the turbidity of the serum, indicates that the substance which occasioned it no longer exists as such in the circulating current; being either drawn-off by the nutritive or secretory operations, or being converted by the assimilating process into the ordinary constituents of the blood.

518. During the passage of the Chyle along the lacteals towards the Mesenteric glands, it undergoes two important changes; the presence of fibrin begins to manifest itself by the spontaneous coagulability of the fluid; and the oil-globules diminish in proportional amount. The fibrin appears to be formed at the expense of the albumen; as this latter ingredient undergoes a slight diminution. It is in the chyle drawn from the neighbourhood of the mesenteric glands, that we first meet with the peculiar floating cells, or chyle-corpuscles (Fig. 92), formerly adverted-to (§ 214),

Fig 92*



in any number. The average diameter of these is about 1-4600th of an inch, but they vary from about 1-7000th to 1-2600th,—that is, from a diameter about half that of the human blood corpuscles, to a size about one-third larger. This variation probably depends in great part upon the period of their growth. They are usually minutely granulated on the surface, seldom exhibiting any regular nuclei, even when treated with acetic acid; but three or four

* Microscopic components of Human Chyle;—A, appearance of chyle as drawn from the thoracic duct, showing *a* the molecular base, *b* fat-particles, *c* chyle-corpuscles,—B, isolated corpuscles, showing at *a*, *b*, *c*, *d*, various stages in the development of the cell-membrane.

central particles may sometimes be distinguished in the larger ones. These corpuscles are particularly abundant in the chyle obtained by puncturing the mesenteric glands themselves; and there can be little doubt that they are identical with the nuclear particles, in various stages of development into cells, which those bodies contain (§ 496).

519. The glandular character of these cells, and their continued presence in the circulating fluid, seem to indicate that they have an important concern in the process of Assimilation,—that is, in the conversion of the crude elements derived from the food, into the organizable matter adapted to the nutrition of the body; one part of this being the conversion of Albumen into Fibrin, which change would seem to take-place to a considerable extent in the Mesenteric glands. For it is only in the Chyle which is drawn from the lacteals intervening between the mesenteric glands and the receptaculum chyli, that the spontaneous coagulability of the fluid is so complete as to produce a perfect separation into *clot* and *serum*. The former is a consistent mass, which, when examined with the microscope, is found to include many of the chyle-corpuscles, each of them being surrounded with a delicate film of oil; the latter bears a close resemblance to the serum of the blood, but has some of the chyle-corpuscles suspended in it. Considerable differences present themselves, however, both in the perfection of the coagulation, and in its duration. Sometimes the chyle sets into a jelly-like mass; which, without any separation into coagulum and serum, liquefies again at the end of half an hour, and remains in this state. The coagulation is usually most complete in the fluid drawn from the receptaculum chyli and thoracic duct; and here the resemblance between the floating cells, and the white or colourless corpuscles of the blood, becomes very striking.

520. The Lymph, or fluid of the Lymphatics, differs from the Chyle, as already remarked, in its comparative transparency: its want of the opacity or opalescence which is characteristic of the latter, being due to the absence, not merely of oil-globules, but also of the 'molecular base.' It contains floating cells, which bear a close resemblance to those of the Chyle on the one hand, and to the colourless corpuscles of the Blood on the other; and these, as in the preceding case, are most numerous in the fluid drawn from the lymphatics which have passed through the glands, and in that obtained from the glands themselves. Lymph coagulates like chyle; a colourless clot being formed, which encloses the greater part of the corpuscles. The Lacteals may be regarded as the Lymphatics of the intestinal walls and mesentery; performing the function of interstitial absorption, as well as effecting the introduction of alimentary substances from without. During the intervals of digestion, they contain a fluid which is in all respects conformable to the lymph of the lymphatic trunks.

521. Thus by the admixture of the aliment newly-introduced from without, with the matter which has been taken-up in the various parts of the system, and by the preparation which these undergo in their course towards the thoracic duct, a fluid is prepared, which bears a strong resemblance to blood in every particular, save the presence of *red* corpuscles. Even these, however, may sometimes be found in the contents of the thoracic duct, in sufficient amount to communicate to them a perceptible red tinge. The fluid of the thoracic duct may be compared to the blood of Invertebrated animals, from which the red corpuscles are almost or altogether absent, but which contains white or colourless corpuscles, and which possesses but a slight coagulating power, in consequence of its small proportion of fibrin. And we hence see why these animals should require no *special* absorbent system; since their blood-vessels convey a fluid, which is itself so analogous to the chyle and lymph to be absorbed, that the latter may be at once introduced into it without injuring its qualities.

5. *Absorption from the External and Pulmonary Surface.*

522. Although the Mucous Membrane of the Alimentary Canal is the *special* channel for the introduction of nutritive or other substances into the system, it is by no means the *only* one. The Skin covering the body, and the Mucous Membrane prolonged into the Lungs, are also capable of absorbing liquids and vapours, and of introducing them into the Circulation; although they serve this purpose less in Man and the higher animals, than in some of the lower. Their utility in this respect is best shown, when, from peculiar circumstances, the function of the digestive cavity cannot be properly performed; and when, therefore, the system has been more than usually drained of its fluids, and stands in need of a fresh supply.—Thus shipwrecked sailors and others who are suffering from thirst owing to the want of fresh water, find it greatly alleviated, or altogether relieved, by dipping their clothes into the sea and putting them on whilst still wet, or by frequently immersing their own bodies. In a case of dysphagia, in which neither solid nor fluid nutriment could be introduced into the stomach, the patient was kept alive for a considerable time, and his sufferings greatly alleviated, by the administration of nutritive clysters, and by the immersion of his body in a bath of tepid milk and water, night and morning. Under this system, the weight of the body, which had previously been rapidly diminishing, remained stationary, although the amount of the excretions was increased; and the use of the bath had a special influence in assuaging the thirst, which was previously distressing. It appeared that the water of the urinary excretion, amounting to from 24 oz. to 36 oz. per day, must have been entirely supplied from this latter source. Again, a man who

had lost nearly 3lbs. by perspiration, during an hour and a quarter's labour in a very hot atmosphere, regained 8 oz. by immersion in a warm bath at 95° for half an hour.—In these cases it appears probable, from the experiments already noticed (§ 502), that the Lymphatics, rather than the blood-vessels, are the chief agents in the absorbing process; not, however, from any powers peculiar to them, but merely on account of the thinness of their walls, and their very copious distribution in the skin.

523. Absorption may also take place from an atmosphere saturated with watery vapour. Of this we have a very curious proof in the Frog; whose urinary bladder (which serves as a sort of reservoir of water) has been observed to be refilled, after having been emptied, by placing the animal in an atmosphere loaded with watery vapour. Numerous instances are on record, which prove that such absorption may take-place in Man to a very considerable extent; though the proportions introduced through the Skin and through the Lungs respectively, cannot be exactly ascertained. The ready introduction of volatile matter into the system, through the latter channel, is a matter of familiar experience; thus if we breathe an atmosphere through which the vapour of turpentine is diffused, it soon produces the characteristic odour of violets in the urinary secretion. And it is probably in this manner, that a large number of those putrescent miasmata and other zymotic poisons are introduced, which are such fertile causes of disease.

6. *Of the Composition and Properties of the Blood.*

524. Having traced the steps by which the Blood is elaborated, and prepared for circulation through the body, and having (in the former part of the volume) inquired into the characters of its chief constituents, we have now to consider the fluid as a whole, to study the usual proportions of these constituents, and the properties which they impart to it.

525. The Blood, whilst circulating in the living vessels, may be seen to consist of a transparent, nearly colourless fluid, termed *Liquor Sanguinis;* wherein the *Corpuscles* to which the blood owes its *red* hue, as well as the white or *colourless* corpuscles, are freely suspended and carried-along by the current.—On the other hand, when the blood has been drawn from the body, and is allowed to remain at rest, a spontaneous coagulation takes place, separating it into Clot and Serum. The Clot is composed of a network of *Fibrin*, in the meshes of which the *Corpuscles*, both red and colourless, are involved; and the Serum is the same with the liquor sanguinis deprived of its fibrin. When the serum is heated, it coagulates, showing the presence of *Albumen*. And if it be exposed to a high temperature, sufficient to decompose the animal matter, a considerable amount of earthy and alkaline *Salts* remains.—Thus

we have four principal components in the Blood;—namely, Fibrin, Albumen, Corpuscles, and Saline matter. In the *circulating* Blood they are thus combined:—

Fibrin, Albumen, Salts	In solution, forming Liquor Sanguinis.
Red Corpuscles	Suspended in Liquor Sanguinis.

But in *coagulated* blood they are thus combined:—

Fibrin, Red Corpuscles	Crassamentum or Clot.
Albumen, Salts	Remaining in solution, forming Serum.

A certain amount of Serum, however, is involved in the Crassamentum; and can only be separated by cutting the clot into thin slices, and carefully washing it.

526. The components of the Blood may be separated, and their amount estimated, in various ways. Thus, if fresh-drawn blood be continually stirred with a stick, or be 'whipped' with a bunch of twigs, the Fibrin coagulates in the form of strings, which adhere to the wood and may thus be withdrawn; whilst the red corpuscles remain suspended in the serum, gradually sinking to the bottom in virtue of their greater specific gravity.—On the other hand, the Red Corpuscles may be separated, in those animals in which they are large enough, by passing the blood through a filter; having previously mingled with it some substance, which retards but does not prevent its coagulation (§ 185).* The liquor sanguinis is thus separated from the blood-discs; and the former coagulates, whilst the blood-discs are retained upon the filter.—The ordinary act of coagulation, by withdrawing the Fibrin and Corpuscles, makes it easy to estimate the proportion of Albumen and of Saline matter in the Blood, when due allowance is made for the quantity of Serum retained in the Clot; and the relative proportions of these may be determined, by evaporating the fluid so as to obtain the whole amount of solid matter it contains, and by then calcining the residuum so as to ascertain how much of this is a Mineral ash, the remainder being chiefly Albumen.—The solid matter of the blood also contains various *Fatty* substances, which may be removed from it by ether. Some of these appear to correspond with the constituents of ordinary Fat (§ 261); whilst another contains phosphorus, and seems allied to the peculiar fatty acids of Neurine (§ 383); and another has some of the properties of Cholesterine, the fatty matter of the Bile (§ 724).—Besides these, there are certain substances known under the name of *Extractive;* one group of which is soluble

* This experiment cannot be performed with Human blood, because the corpuscles are small enough to pass through the pores of any filter that allows the liquor sanguinis to permeate it; but it answers very well with Frog's blood.

in water, and another in Alcohol. Of the precise nature of these, little is known. They have been aptly termed 'ill-defined' animal principles; and it is probable that they may include various substances in a state of change or disintegration, which are being eliminated from the Blood by the processes of Excretion. The advance of Chemical knowledge, however, is gradually leading to the detection of definitely-known substances in the extractive of the blood; especially of those excretory matters which are destined for elimination by the kidneys, such as urea, uric acid, creatine, creatinine, and hippuric acid.

527. The general result of numerous recent analyses of the Blood may be thus stated:*—The whole amount of solid matter is rather greater in the Male than in the Female; being, on the average, about 210 parts in 1000 in the former, and 190 in the latter. This difference, however, chiefly depends on the larger proportion of red corpuscles contained in the blood of the male.—The proportion of Albumen seems more constant than that of the other constituents of Blood; seldom varying beyond 5 or 6 parts, in either sex, above or below 70 in 1000.—The quantity of Corpuscles appears liable to considerably greater variation; the superiority on the side of the Male, however, being very strongly marked in the maximum and minimum, as well as in the average. We may regard its average in the Male as about 132 in 1000 parts of blood; but it may fall to 110·5 parts, without the health being seriously affected; whilst, on the other hand, it may rise to 186 without any manifestation of disease. In the Female, its average may be about 120 parts in 1000; but it may fall to as little as 71·4, and may rise to 167, consistently with ordinary health. The range of variation is thus much greater in the Female than in the Male; the minimum being considerably less, in the former, than half the maximum; whilst in the latter, it is much more. This is probably due in part to the

* The proportions above given are those commonly assigned on the basis of analyses made by Prof. Andral's method. They are, however, subject to the fallacy that all the water of the corpuscles is computed as holding in solution the solids of the serum; and the latter are consequently estimated too high, whilst the solids of the corpuscles are reduced to a lower proportion than they really bear. According to the estimates of Schmidt and Lehmann, based on separate analyses of the Corpuscles and of the Liquor Sanguinis, when the total volume of *moist* Corpuscles is 50 per cent. of the entire volume of the blood (which may be considered as about an average proportion), the relative amounts of *dry* solids will be, in round numbers, as follows:—

Fibrin	2
Corpuscles	150
Albumen	40
Fatty and Extractive Matters	5
Salts	8
Total Solids	205
Water	795
	1000

fact, that the loss by the Catamenial discharge may produce a great temporary depression in the proportion of the Corpuscles.—The average proportion of Fibrin seems to be no more than 2·5 in the Male; and though it may rise to as much as 3·5 or even 4, without disordering the system, it does not seem to fall below 2, in the state of ordinary health. The average in the Female is probably about 2·3; the proportion may rise to 3, or fall to 1·8; but the variation seems less considerable in the Female than in the Male.—Much is probably yet to be learned, regarding the influence of different kinds of food recently taken, on the proportion of these constituents of the blood; and it does not seem unlikely from what has been already stated (§ 517), that the quantity of fatty matter is especially liable to variation, in accordance with the amount contained in the food, and the time which has elapsed since the last meal.

528. The Saline constituents of the blood, obtained by drying and incinerating the whole mass, usually amount to between 6 and 7 parts in 1000. More than half of their total quantity is composed of the Chlorides of Sodium and Potassium; and the remainder is made-up of the tribasic Phosphate of Soda, the Phosphates of Lime and Magnesia, Sulphate of Soda, and a little Phosphate and Oxide of Iron. Of these the chief part are dissolved in the Serum; but the Earthy Phosphates, which are insoluble by themselves, are probably combined with the protein-compounds (§ 175); and the Iron is contained, chiefly or entirely, in the red corpuscles. It is difficult to speak with certainty, from the examination of the *ashes* of the blood, as to the state of the saline constituents of the circulating *fluid*. Thus, the Serum has an alkaline reaction; and this has been supposed to be due to the presence of alkaline Carbonates. Moreover, the presence of the Lactates of potash and soda seems probable; for it is certain that lactic acid is normally introduced into the blood, and is also eliminated from it; and the rapidity with which the lactates are removed as such, or are converted into carbonates, seems to afford a sufficient explanation of the difficulty in demonstrating the presence of this acid in the circulating fluid. Although the ashes of the entire mass of blood do not effervesce on the addition of an acid, effervescence takes-place when acid is added to the ashes of the Serum; showing the existence in it, either of alkaline Carbonates, or of Lactates which have been reduced to the state of Carbonates by incineration. When the entire mass of blood is incinerated, however, enough phosphoric acid is produced from the phosphorized fats, to neutralize the alkaline carbonates, and thus to prevent their presence from being recognized. The alkaline reaction of the blood, however, is certainly dependent in part upon the presence of the tribasic phosphate of soda, which appears to confer upon the serum a special power of absorbing carbonic acid.

529. The following appear, from the considerations stated in the preceding part of this treatise, to be the chief uses of the principal

constituents of the Blood, in the general economy. The Fibrin is the material which is most assimilated to the condition of the solid tissues, and hence constitutes an essential part of every organizable exudation. But, although it was formerly supposed to be the immediate pabulum of *all* the tissues, there seems to be now much reason to limit its utility to the production of those simple forms of fibrous or connective substance, the production of which is the first step in the reparation of injuries. Moreover, if a proper amount of Fibrin be not present in the Blood, the physical properties of the liquid are so far altered by the diminution of its viscidity, that it will not circulate through the capillaries as readily as before; a certain degree of viscidity having been experimentally found to be favourable to the movement of fluid through glass or metallic tubes of small bore.—The Albumen of the blood is the raw material, at the expense of which not only the Fibrin, but many other substances are generated during the nutritive process; and it is probably at the immediate expense of this component of the blood that the cellular tissues of the body are developed, as they are in the Ovum at the expense of the store of Albumen laid-up in it. Further, all the Albuminous compounds of the Secretions, the Horny matter of the Epidermic tissues, the solid materials of the Red Corpuscles, and other substances, may be regarded as almost certainly produced by the transformation of the Albumen of the Blood; and a continual supply of this from the food is therefore requisite, to preserve the due proportion in the circulating fluid.—The Red Corpuscles, which (it will be remembered) are almost exclusively confined to Vertebrated animals, appear to be as much connected with the function of Respiration, as with that of Nutrition; but there are indications, in their peculiar chemical composition, that they prepare special materials for the nutrition of the Nervous and Muscular systems; and the stimulating action of Arterial blood upon those tissues, appears chiefly to depend upon their presence. It has been observed in particular, that their presence is more effectual in stimulating the heart's action, than is that of either of the other constituents of the blood. In addition to what has been already stated (§ 219), in reference to their continual disintegration and renewal, it may be mentioned that when the blood of one animal was injected by Magendie into the veins of another having discs of very different size and form, the original Red corpuscles soon disappeared, and were replaced by those characteristic of the species in whose veins the fluid was circulating.

530. The use of the Saline matter is evidently in part to prevent decomposition in the circulating Blood, but also to supply the mineral materials requisite for the generation of the tissues and entering into the composition of the secretions. It is by the saline and albuminous matters in conjunction, that the specific gravity of the Liquor Sanguinis is kept-up to the point at which it is equiva-

lent to that of the contents of the Red Corpuscles; and it is only in this condition, that the formation of the latter can duly take-place. —The Fatty matters of the Blood are evidently derived from the food, either directly, or by a transformation of its farinaceous ingredients (§ 430); and they are chiefly appropriated to the maintenance of the combustive process. But there is reason to believe, that Oleaginous matter performs a most important part in the incipient stages of Animal nutrition; and that its presence is not less essential to the generation of cells, than is that of the albuminous matter which forms their chief component, all *nuclei* being observed to include fatty particles. That which may be superfluous is either deposited in the cells of Adipose Tissue, or it is eliminated by the Liver, the Sebaceous follicles of the Skin, and, in the female when nursing, by the Mammary glands.

531. The proportion of these components of the Blood is liable to undergo changes in disease, which extend far beyond the widest limits which have been mentioned as consistent with health. Thus, the quantity of Fibrin exhibits a remarkable *increase* in Inflammation; the amount then found in the blood rising from 5 or 6 parts in 1000, to 9, 10, or even 10½, according to the extent and intensity of the disease. On the other hand, it presents a remarkable *diminution* in Typhoid fevers; the quantity being sometimes as little as 0·9. If any decided Inflammation should develope itself, however, in the course of the Fever, the proportion of fibrin rises accordingly. A deficiency of fibrin in the blood predisposes to Hæmorrhages, Congestions, &c., either in the substance of the tissues, or on the surface of membranes; and these conditions are well known to be of frequent occurrence as complications of febrile disorders. An excess of fibrin is not much affected by copious bleeding, even if this be frequently repeated; but there is reason to think that the administration of Mercury has a tendency to restrain its production.

532. It is difficult to say what amount of Red Corpuscles should be regarded at excessive; since, as we have seen, they may augment to a great degree, without disturbing the health. When they are present in an amount much above the average, they seem concerned in producing the condition termed Plethora; which marks a 'high condition' of the system, and which borders upon various diseases, especially those of Congestion, and Hæmorrhages. To these a peculiar liability then exists; because, although the proportion of Fibrin in the blood is not absolutely low, it is low in reference to that of the Red Corpuscles. Plethoric persons do not seem more liable to Inflammation, than are those of weakly constitution. The quantity of the Red Corpuscles is rapidly diminished by frequent bleeding; and hence it is lowered by repeated Hæmorrhages. On the other hand, it is speedily restored to its usual standard under the influence of nutritious diet, if the digestive powers have not been

too much weakened to make use of this.—The proportion of Red Corpuscles undergoes a marked diminution in various forms of Anæmia; and particularly in Chlorosis. In severe cases of this latter disease, it has been found as low as 27 in 1000; and it not unfrequently sinks to 40 or 50. The marked influence of the administration of Iron, in favouring the reproduction of Red Corpuscles, has been already noticed (§ 219).

533. The proportion of Albumen in the Blood seems less liable to change, except in the condition termed Albuminuria, in which a large quantity of albumen appears in the Urine. When this condition is permanently established, it is indicative of the existence of serious organic disease of the kidney; but it may occur for a short time under the influence of simple congestion of that organ, which causes an escape of the albuminous part of the blood, together with the water which is filtered-off (as it were) in this gland (§ 728). Now when Albuminuria is fully established, there is a marked diminution in the quantity of albumen in the serum of the blood; and this diminution is constantly proportional to the amount of albumen present in the urine.—The proportion of Saline matter appears to undergo less alteration in disease, than that of the other constituents of the Blood; and has not been found to have a regular correspondence, either in the way of excess or diminution, with any particular morbid state.

534. The condition of the Blood may be affected, not merely by alteration in the proportions of its normal ingredients, but by the presence of other substances;—either such as are generated in it, and are constantly being eliminated from it in health, but have accumulated to an abnormal degree;—or such as have found their way into it from without. Thus, Carbonic Acid, Urea and Lithic Acid, Cholesterine and other elements of Bile, and other matters which it is the office of the Excreting organs to remove, may accumulate in the blood, and may become fertile sources of disease, by their injurious influence. The introduction of various Mineral substances, by absorption from without, changes the composition of the normal elements of the Blood, and thus affects their vital properties; thus strong saline solutions diminish or destroy the coagulating power of the Fibrin. But the most remarkable cases of depravation of the Blood, by the introduction of matters from without, are those which result from the action of *ferments*,—exciting such Chemical changes in the constitution of the fluid, that its whole character is speedily changed, and its vital properties are altogether destroyed. Of such an occurrence we have a marked example in the various forms of malignant fevers; in which the introduction of a very minute quantity of noxious matter into the blood, either through the lungs or through the skin, produces a speedy alteration in the characters of the whole mass of the blood, the function of every organ in the body is disordered, and decom-

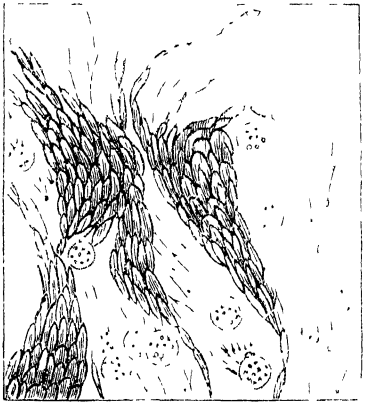
position of the solids and fluids takes-place to a considerable extent, even before the circulation ceases, and whilst consciousness yet remains. The train of symptoms produced by the bite of venomous Serpents and of rabid animals, appears referable to the same cause, —the alteration in the condition of the whole current of blood, by the introduction of a minute quantity of a substance that acts as a 'ferment.'

535. The Coagulation of the Blood, as already explained, depends upon the passage of its Fibrin from the fluid state to the solid (§ 181); consequently, if the fibrin be separated from the other elements, no coagulation takes place. On the other hand, if the amount of fibrin be larger than ordinary, the coagulum possesses an unusual degree of firmness. The length of time which elapses before coagulation, and the degree in which the clot solidifies, vary considerably; in general they are in the inverse proportion to each other. Thus, if a large quantity of blood be withdrawn from the vessels of an animal at the same time, or within short intervals, the portions that last flow coagulate much more rapidly, but much less firmly, than those first obtained, in consequence of the diminished proportion of fibrin. On the other hand, when the fibrin is in excess, its coagulation is unusually delayed. From this delay an important change results in the mode in which the coagulation takes-place; for the red corpuscles, instead of being uniformly diffused through the coagulum, have time to sink to the bottom, in virtue of their greater specific gravity; and the upper part of the clot is consequently made-up of Fibrin almost exclusively, whilst the lower is chiefly formed by the aggregation of the red corpuscles. Hence the upper layer is almost destitute of colour (whence it has received the name of *buffy coat*), and is remarkably tenacious in its character; whilst the lower is very deep in hue, and very friable in consistence. When the fibrillated net-work forming the buffy coat undergoes that slow contraction, which is characteristic of highly-elaborated fibrin subsequently to its coagulation, it draws-in the edges of the upper surface of the clot, giving it a *cupped* appearance.

536. The Buffy Coat may present itself under a great variety of conditions; and it can no longer, therefore, be considered (as it formerly was) a sign of the Inflammatory state. It is most fully developed when acute Inflammation exists; because in that condition *all* the circumstances which favour it are present. That it may be produced by any cause which occasions delay in the coagulation of the blood, is evident from the fact, that healthy blood may be made to exhibit it, by adding a solution of a neutral salt, which retards but does not prevent its coagulation. But the blood may coagulate with its ordinary rapidity, or even more speedily than usual, and may yet exhibit the Buffy coat. And, moreover, the separation of the Fibrin and the Red Corpuscles may take-place in

films of blood so thin as not to admit of a stratum of one being laid over the other; the two elements separating from each other laterally, and the films acquiring a speckled or mottled appearance, equally characteristic of the Inflammatory condition with the Buffy coat itself. Hence the separation must be due in such cases, to other causes than gravity; and recent observations have accounted for it, by showing that the Red Corpuscles have an unusual attraction for one another in the inflammatory state, causing their coalescence in piles and masses; whilst the particles of Fibrin have also a peculiarly strong attraction for each other. Thus there is a powerful tendency that draws-together the components of each kind, and consequently separates them from the others; and when this separation takes-place, the difference in the specific gravity of the two elements decides their respective situations.—The peculiar tendency of the Red corpuscles to unite, in the Inflammatory state, serves to mark the existence of this condition, even in a single drop of blood; and it is then that the White corpuscles may be most easily distinguished, as they are seen apart from the rest of the mass, having no tendency to unite with it (Fig. 93). In fact, the white corpuscles

*Fig. 93.**



are not found in company with the red, in the ordinary coagulum, but rather with the fibrinous portion; and when they are peculiarly

* The microscopic appearance of a drop of Blood in the Inflammatory condition. The *red* corpuscles lose their circular form, and adhere together, the *white* corpuscles remain apart, and are more abundant than usual.

abundant, as they usually are in Inflammatory blood, they may form a considerable proportion of the buffy coat.

537. The Buffy Coat may present itself, without the least increase in the normal quantity of Fibrin, and without any approach to the Inflammatory state: simply because the fibrin is present in excessive amount, in relation to the amount of red corpuscles, the latter being much below their usual proportion. Thus in severe Chlorosis, the buffy coat is almost as strongly marked as in the severest Inflammation; but the two conditions are at once distinguished by the relative proportions of solid matter in the blood, as indicated by the size of the coagulum. For in Chlorosis, the coagulum is very small, in consequence of the reduced proportion of corpuscles, and is almost invariably found floating in the serum; whilst in the ordinary Inflammatory condition, it is of full size, frequently adhering to the side of the vessel.

CHAPTER VI.

OF THE CIRCULATION OF THE BLOOD.

1. *Nature and Objects of the Circulation of Nutrient Fluid.*

538. The nutritive fluid,—the elements of which are thus partly taken-up and prepared by the Absorbent system, but in great part also imbibed through the Blood-vessels distributed upon the walls of the digestive cavity, and assimilated by the liver (§ 493),—is carried into the various parts of the system by the act of Circulation. This movement answers various purposes. It furnishes all the tissues which are to derive nutriment from the Blood, with a constantly-renewed supply of the materials which they severally require; and in this manner it is subservient to the growth, not only of those tissues which form part of the solid structure of the body, but also of those various cells covering its free surfaces, which are continually being cast-off and renewed, and which, in the course of their development, separate from the blood the products that are to perform ulterior purposes in the economy, or are to be removed as altogether effete. Thus the Circulation is subservient to the functions of Nutrition and Secretion. In the exercise of these functions, different materials are drawn from the blood by the several tissues it supplies. Thus the nutrition of the muscle requires fibrin; that of the nerve draws-off fatty matter; that of the bone requires gelatine and earthy salts; that of the hepatic cells removes the fatty matter and other

elements of bile; that of the milk-cells (during lactation) separates albuminous, fatty, and saccharine substances;—and so on. Thus various portions of the blood, when returning from the several organs through which they have been transmitted, have undergone very different changes by the nutritive and secreting processes, according to the function of the organs which they have supplied; and if the same portion of the circulating fluid were constantly being transmitted to each organ, and returned from it, its composition would speedily undergo a change that would render it no longer fit for its purposes. By the union of the different local circulations, however, into one general circulation, this change is prevented, and the whole mass of the blood is maintained in its normal or regular condition; for since its composition is such as to supply all parts of the body, in a state of health, with the proportions of nutritive material which they respectively need; and since the returning currents are all mingled-together in the vessels, before being again distributed to the system, each part supplies what the other has been deprived-of, and thus the normal proportion of ingredients in the whole mass of the blood is constantly kept-up, whilst in each of its separate streams it is undergoing an alteration of a different kind.

539. But these processes alone might be carried-on by the aid of a much less rapid Circulation, than that which exists in Man and the higher animals. We do, in fact, occasionally meet with examples in which they continue for some time, under an almost total stagnation of the current. There are others, however, which require a much more rapid and uninterrupted movement of the circulating fluid. We have already seen that, for the *action* of the Nervous and Muscular tissues, *oxygen* is necessary; and the amount of that gas contained in the blood circulating through these tissues would be very speedily exhausted, if it were not continually renewed; whilst the carbonic acid which is formed at the expense of that oxygen, would speedily accumulate to an injurious degree, if it were not carried-off as fast as it is produced. Hence we find that, in all Animals, the maintenance of the Respiration, by carrying Oxygen from the respiratory surface into the different parts of the system, and by conveying-back Carbonic acid to be thrown-off at the Respiratory surface, is one of the great purposes of the Circulation of the blood; and its extreme importance is shown by the very speedy check which the interruption of this function produces in the movement of the blood, in warm-blooded animals. Thus in a Bird or Mammal, completely cut-off from Oxygen, the circulation in the lungs will come to a stop, which stoppage will necessarily extend itself over the whole body, in little more than three minutes. We find, then, that the rate of the Circulation in different animals bears a relation to the energy of their Respiration; and this energy is closely connected with the general activity of their functions, but particularly with that of the Nervous and

Muscular systems, which are most dependent for the exercise of their powers upon a continually-renewed supply of oxygen, and upon the unceasing removal of the carbonic acid which is generated in their substance.

2. *Different forms of the Circulating Apparatus.*

540. It is desirable that the Circulating apparatus should be first studied in its very simplest form,—that which it possesses in Plants and in the lowest tribes of Animals; as in this way alone can the forces which are concerned in the movement of the fluid, be rightly appreciated. In all the higher Plants, the *ascending* or crude sap is to be distinguished from the elaborated or *descending* sap. The former of these fluids should be compared rather with the chyle than with the blood of Animals; for it is not yet fully prepared to take-part in the nutrition and extension of the structure. But there are some circumstances attending its movement, which throw light upon other more complicated phenomena. The ascending sap consists principally of water, which is imbibed, together with various substances which it holds in solution, by the delicate tissue at the soft extremities of the root-fibres or 'spongioles.' The power of forcing-upwards a column of sap, which exists in these bodies, and which seems due to Endosmose (§ 491), is shown by very simple experiments. If the stem of a Vine, or of any tree in which the sap rises rapidly, be cut-across when in full leaf, the sap continues to flow from the lower extremity; and this with such force, as to distend with violence, or even to burst, a bladder tied firmly over the cut surface. If, instead of a bladder, a bent tube be attached to this, and mercury be poured into it so as to indicate the pressure exerted, it is found that the rise of the sap takes-place with a force equal to the pressure of from one to three atmospheres (from 15 to 45 lbs. upon the square inch)—or even more. Thus the ascent of the sap is partly due to a powerful *vis a tergo*, or impelling influence, derived from the point at which the absorption takes-place.

541. But, on the other hand, if the upper part of the stem be placed with its cut surface in water, a continued absorption of that fluid will take-place, as is evinced by the withdrawal of the water from the vessel; the fluid which is thus taken-up, however, is not retained within the stem and branches, but is carried into the leaves, and is thence dissipated by exhalation. It is obvious, then, that the *vis a tergo* is not the sole cause of the ascent of the sap; but that a *vis a fronte* also exists, by which the fluid is drawn towards the parts in which it is to be employed. This is further made apparent by a few simple experiments. If a branch, when thus actively absorbing fluid, be carried into a dark room, the absorption and ascent of fluid immediately cease almost

completely; and are renewed again, so soon as the leaves are again exposed to light. Now we know from other experiments, that light stimulates the exhaling process (§ 87), whilst darkness checks it; and the cessation of the demand in the leaves thus produces a cessation in the absorption at the lower extremity of the stem. And this is the case, also, in the natural condition of the plant; as is easily shown by immersing the roots in water, and observing the respective quantities which are removed by absorption during sunshine, shade, and darkness. On the other hand, the movement of the sap may be excited, when it would not otherwise take-place, by the production of a demand at the extremities of the branches; thus if a branch of a vine growing in the open air, be introduced into a hothouse, and be subjected to artificial heat during winter, its buds will be developed, its leaves will expand, and these will draw fluid to themselves through the roots and stems, which are still inactive as regards the remainder of the tree. And the natural commencement of that movement of the ascending sap which takes place with the returning warmth of spring, has been experimentally shown to occur, in the first instance, not in the neighbourhood of the roots, but nearest the extremities of the branches; the exhalation of fluid from the expanding buds being the first process, and a demand for fluid being thus created, which is supplied by the flow that is thus excited in the lower part of the stem,—this, again, being supplied from the roots, which are thus caused to recommence their absorbent function.

542. Thus we see that, in the 'ascending sap,' the movement is entirely regulated by the demand for fluid occasioned by the actions of the leaves; even though it is in great part dependent on the *vis a tergo* which has its seat in the spongioles. Not even this force, however,—powerful as it has been shown to be,—can produce the continuance of the upward flow, when the exhalation from the leaves is checked by darkness, and when the demand occasioned by the action of these organs is consequently suspended.

543. The movement of the 'descending sap' offers numerous points which deserve to be carefully considered. This fluid is strictly comparable to the blood of animals; having undergone a preparation or elaboration in the leaves, which adapts it to the nutrition and extension of the structure, and to the formation of the various secretions of the plant. A great part of the fluid of the ascending sap has been lost by exhalation: and the remainder, thus concentrated, receives a large additional supply of solid matter through the agency of the green cells of the leafy parts, which take-in carbon from the atmosphere (§ 83); so that it now includes a considerable amount of plasmatic material in a state of preparation for being converted into solid tissue, as well as other compounds. Now this 'elaborated sap' seems to be conveyed into the various portions of the system, partly by transmission from one cell to another,

but partly through the agency of a network of vessels, which takes its origin in the leaves, and extends along the branches to the stem and roots, chiefly in the bark of those parts. These vessels are strictly analogous to the *capillaries* or smallest blood-vessels of Animals; but they differ from them in this,—that the capillary network of Animals communicates on either side with larger trunks, being formed, in fact, by the interlacement or anastomosis of their minutest branches,—whilst the network of nutritive vessels in Plants is everywhere continuous with itself, not having any communication with large vessels, so that the fluid prepared in the leaves commences a circulation there, which is continued on the same plan until it has found its way to its remote destination in the roots.

544. The natural movement of the 'elaborated sap' through these vessels may be studied, under favourable circumstances, with the assistance of the microscope; the requisite conditions being that the part should be sufficiently transparent for its vessels to be distinctly seen, that the sap shall contain globules in sufficient number to allow its movement to be distinguished by their means, and that the circulation should be observed without the separation of the organ examined from the rest of the Plant, which would produce irregular movements by the escape of the sap from the wounded part. These conditions may be attained in many Plants; —most conveniently, perhaps, in the stipules of the *Ficus elastica*, one of the trees which affords the largest supplies of Caoutchouc; and it is then found that the movement takes-place in the following manner. Distinct currents are seen, passing along the straightest and most continuous vessels, and crossing by the lateral connecting branches of the network. These currents follow no determinate direction; some proceeding up, and others down; some to the left, and others to the right: not unfrequently a complete stoppage is seen in one or more of the channels, without any obvious obstruction; and the movement then recommences, perhaps in the opposite direction. The influence of a force developed in the act of circulation, which determines the direction of the movement, appears from this; that if a tube be cut-off, so as to give its contents an equally free exit at both ends, the sap only flows-out at one extremity. The movement is retarded by lowering the temperature of the surrounding air, and it is completely checked by extreme cold; it is capable of being renewed by moderate warmth; and a further addition of heat increases its rapidity. By a strong electric shock, the force by which the liquid is propelled seems to be altogether destroyed; for the movement then ceases entirely.

545. Now it is quite certain that this circulation cannot be due to any *vis a tergo;* both because it is not constant in its direction in particular vessels; and because there is no organ in which any propelling force, that could extend itself through such a complex

system of vessels, may be developed. Nor can it be in any way due to the force of gravity; for although this may assist the descent of the fluid through the stem, it is totally opposed to its ascent from the ends of its branches towards their origin, when, as often happens, the latter are at the higher level. Moreover, it may be noticed that this circulation takes-place most readily, in parts that are undergoing a rapid development; and that its energy corresponds with the vitality of the part. Further, it may be observed to continue for some time in parts that have been completely detached from the rest, and on which neither *vis a tergo* nor *vis a fronte* can have any influence. It is evident, then, that the force—whatever be its nature,—by which this continued movement is kept-up, must be developed by the processes to which that movement is subservient; in other words, that the changes involved in the acts of nutrition and secretion are the real source of the motor power. The manner in which they become so is the next object of our inquiry; and on this subject, some views have been put-forth by Prof. Draper, which seem to account well for the phenomena.

546. It is capable of being shown, by experiments on Inorganic bodies, that, if two liquids communicate with each other through a capillary tube, for the walls of which they both have an affinity, but this affinity be stronger in the one liquid than in the other, a movement will ensue; the liquid which has the greatest affinity being absorbed most energetically into the tube, and driving the other before it. The same result occurs when the fluid is drawn, not into a single tube, but into a network of tubes permeating a solid structure; for if this porous structure be previously saturated with the fluid for which it has the less degree of attraction, this will be driven-out and replaced by that for which it has the greater affinity, when it is permitted to absorb this. Now if, in its passage through the porous solid, the liquid undergo such a change that its affinity is diminished, it is obvious that, according to the principle just explained, it must be driven-out by a fresh supply of the original liquid, and that thus a continual movement in the same direction would be produced.

547. Now this is precisely that which seems to take-place in the organized tissues permeated by nutritious fluid. The particles of this fluid, and the solid matter through which it is distributed, have a certain affinity for each other, which is exercised in the nutritive changes to which the fluid becomes subservient during the course of its circulation. Certain matters are drawn from it, in one part, for the support and increase of the woody tissue; in another part, the secreting cells demand the materials which are requisite for their growth,—as starch, oil, resin, &c.; and thus in every part that is traversed by the vessels, there are certain affinities between the solids and the fluids, which are continually being developed afresh by acts of growth, as fast as those which previously existed are

satisfied or neutralized by the changes that have already occurred. Thus in the circulation of the elaborated sap, there is a constant attraction of its particles towards the walls of the vessels, and a continual series of changes produced in the fluid as the result of that attraction. The fluid, which has given-up to a certain tissue some of its materials, no longer has the same attraction for that tissue; and it is consequently driven from it by the superior attraction then possessed by the tissue for another portion of the fluid, which is ready to undergo the same changes, to be in its turn rejected for a fresh supply. Thus in a growing part, there is a constantly-renewed attraction for the nutritive fluid which has not yet traversed it; whilst, on the other hand, there is a diminished attraction for that fluid which has yielded-up the nutritive materials required by the particular tissues of the part; and thus the former is continually driving the latter before it.

548. But the fluid which is thus repelled from one part, may still be attracted towards another; because that portion of its contents which the latter requires, may not yet have been removed from it. And in this manner, it would seem, the flow of sap is maintained through the whole capillary network, until it be altogether exhausted of its nutritive matter. The source of the movement is thus entirely to be looked-for in the changes which take-place in the act of growth; and the influence of heat, cold, and other agents, upon the movement, is exercised through their power of accelerating or retarding those changes.—The fluid which thus descends through the stem and roots, seems to be at last almost entirely exhausted; a portion of it appears to find its way into the interior of the stem, and to be mingled with the ascending current; but all the rest seems to have been entirely appropriated by the different tissues through which it has circulated. Thus there is no need of any general receptacle into which it may be collected, and from which it may take a fresh departure;—such as is afforded by the heart of Animals. And as the purpose of this circulation is only to supply the nutritive materials, and not to convey oxygen,—this element being but little required in the vegetative processes, and being supplied by other means,—the same energy and rapidity are not required in it, as need to be provided-for in the higher Animals.

549. A condition of the Circulating system very similar to this, exists in several of the lower animals, as well as in the embryo-state of the higher. In the very lowest no blood-vessels are required, for the same reason that no sap-vessels exist in the lowest Plants;—namely, because every part absorbs and assimilates nutritious fluid for itself, so that it does not require a supply from vessels. As in the Sea-weeds the whole substance is nourished by direct absorption from the fluid in contact with the *external* surface, every part of which seems endowed with the like absorbent power, so in *Zoophytes* do we find that the whole substance is nourished by

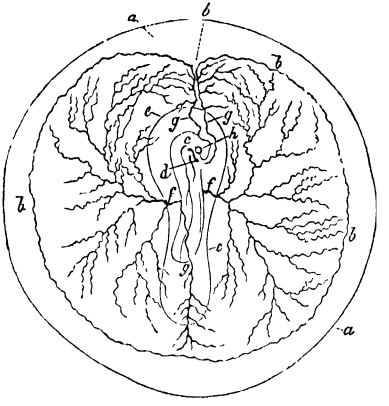
direct absorption from the *internal* surface, which forms the lining of the digestive cavity. In the same manner, the Aeration of the animal fluids,—or the exposure of them to the air contained in water, by which they may part-with carbonic acid and imbibe oxygen,—is provided-for, not by any special respiratory organs, but by the contact of water with every portion of the soft external and internal surfaces. Further, as the substance of their body is nearly of the same kind in every part, they do not require the continual interchange of the fluid distributed to its several portions. Hence no circulation is necessary, in these simple animals, either for the nutrition of their tissues, or for the aeration of the fluids. The same is the case with others of the lower tribes, as well as with the embryo of the higher Animals at the earlier periods of their development. Thus the lowest *Entozoa*, or parasitic worms, have a digestive cavity channelled-out, as it were, in their soft gelatinous tissues; and from the walls of this, the nourishment is drawn by the several component parts of those tissues, without the mediation of vessels. And the embryo even of Man, in its early condition, consists of an aggregation of cells, each of which absorbs for itself from the nutritious fluid with which it is surrounded, and goes through all its functions independently of the rest.

550. Proceeding a little higher, we find the first appearance of proper vessels in the *Echinodermata* (Star-fish and Sea-urchin tribe). These vessels seem to take-up the nutritive fluid from the walls of the digestive cavity on which they are spread-out, just as the roots of Plants do from the soil. They then unite into trunks, by which the fluid is conveyed to the more distant parts of the structure, in the same manner as the ascending sap is conveyed to the leaves by the vessels of the stem and branches: and these trunks again subdivide, and form a network of capillary vessels, which are dispersed through the several parts of the fabric; some of them being very abundantly distributed upon a portion of the surface, which is particularly destined to perform the respiratory function. Through these capillary vessels, the fluid seems to move in very much the same manner as through the system of anastomosing vessels in Plants;—that is, its motion is due rather to forces which are developed during its circulation, than to any *vis a tergo* derived from the contractile power of a propelling organ. But there is this difference; that, after having traversed the minute vessels, and yielded-up to the tissues a part of the solid matter which it contains, the fluid is collected again by other trunks, which convey it back to the point from which it started; there it is mingled with the fluid that has been newly absorbed, and with that which has undergone aeration; and it is then distributed, as before, through the general capillary network of the body.

551. Now this is very much the condition of the Human embryo, at the time when vessels are first developed in its substance. These

vessels are formed by the coalescence of cells; and from the contents of these cells, which have been imbibed from the yolk, the first blood seems to be derived. The first formation of blood-vessels takes place, not in that part of the embryonic structure which is to be developed into the perfect animal, but in a membranous expansion from it, which surrounds the yolk, and which answers the purpose of a temporary stomach. A capillary network is formed in a limited portion of this membrane, termed the *vascular area* (Fig. 94); and

Fig. 94.*



this does not originate in the branching of larger trunks, these trunks being subsequently formed by the reunion of the capillaries. The first movement of the blood is *towards* the central spot in which the organs of the permanent structure are being evolved; and it takes place before the incipient heart has acquired any muscularity, so that it must be quite independent of any contractile force exerted by that organ. Here, too, we perceive that the circulation is essentially *capillary*, and that it is sustained by forces very different from those of which the action is most evident to us in the higher animals.

552. As we ascend the animal scale, however, we find that provision is made for a more regular and vigorous Circulation of the Blood, than that which exists in the lowest classes. Even in the

* Vascular area of Fowl's egg, at the beginning of the third day of incubation;—*a*, *a*, yolk; *b*, *b*, *b*, *b*, venous sinus bounding the area; *c*, aorta; *d*, punctum saliens, or incipient heart; *e*, *e*, area pellucida; *f*, *f*, arteries of the vascular area; *g*, *g*, veins; *h*, eye.

class of *Echinodermata*, a portion of the principal vessel is peculiarly endowed with contractile power; and this may be seen in constant pulsation, like the heart of the higher animals, alternately contracting to propel the fluid it contains through the vessels that issue from it, and then dilating to receive a fresh supply from the vessels that pour their contents into it. It seems quite certain, however, from the extent of the vascular system of these animals, that the influence of such a pulsatile cavity must be quite insufficient to keep-up the movement of blood through it. A similar provision is observable in the lower tribes of *Worms*, in which this contractile vessel lies along the back; propelling the blood forwards, by a sort of peristaltic movement, through trunks which pass-out at its anterior termination; and receiving it again, after it has circulated through the system, by vessels which enter at its posterior extremity. In the higher orders of Worms, in the *Myriapoda* or Centipede tribe, and in *Insects*, we find this dorsal vessel divided by transverse partitions containing valves, into separate cavities which answer to the different segments of the body. Each of these is, to a certain extent, the heart of its own segment, receiving and propelling blood by trunks which open into it; but they all participate in the more general circulation just described, a large portion of the blood being poured into the hindermost segment, transmitted forwards from cavity to cavity through the valves which separate them, and at last propelled through trunks that issue from the most anterior segment. In some instances we find that two or three of these trunks, on either side, pass round the œsophagus, and reunite below it, so as to enclose it in a sort of collar; and they form a main trunk by this union, which runs backwards along the under surface of the body, and which distributes the blood to its different organs by lateral branches. These subdivide into a capillary network; and the returning vessels which originate in this network, pour the blood which has circulated through it into the posterior cavity of the dorsal vessel.—Still it is very evident, from the observation of the movement in those transparent species in which the whole process can be distinctly watched under the Microscope, that the contractile power of the dorsal vessel is far from sufficient of itself to sustain the Circulation; and that the flow of the blood through the capillary network is in part due to forces developed during its progress, being often retarded or accelerated in particular spots, without any visible change in the propelling force of the central organ. Moreover, the blood, during some part of its course, almost always escapes from the proper vessels into *lacunæ* channelled among the tissues; and over its flow through these, no central impelling organ can have much influence.

553. In most of these animals there are distinct organs of Respiration, confined to some one part of the body; and we often find that the vessels which convey blood to them, are furnished with

distinct contractile portions, like so many supplementary hearts, for the purpose of propelling the blood through them more energetically. In proportion as we ascend the series of Articulated animals, do we find, for the most part, a more vigorous and regular circulation, both for the nutrition of the system, and for the transmission of the blood through the respiratory organs; but there is an exception in the case of *Insects*, which deserves special notice. In this class, the circulation is much less vigorous than it is in other Articulated animals of similar complexity of structure; though it might have been anticipated that the extraordinary activity of their movements would necessitate a corresponding rapidity in the circulating current, especially for the purpose of conveying an extraordinary supply of oxygen to the nervous and muscular systems. But this is provided-for in another way; the air being conveyed to these tissues, not through the blood, but by direct transmission through the minute ramifications of the air-tubes or tracheæ, which penetrate the very smallest organs of the body (§ 659).

554. The condition of the Circulating apparatus in the Embryo of higher animals, at a period a little advanced beyond that already alluded-to, presents a striking analogy with that last described; for the heart, at the time of its first formation, seems like a mere dilatation of the principal vascular trunk, having thickened walls, in which, after a time, muscular fibre begins to be developed, and the contractile power manifests itself. The pulsation of this heart, however, does not seem to extend its influence immediately through the vascular area; the capillary circulation in which remains for some time in great degree independent of it. There is no resemblance in *form*, however, between the dorsal vessel of Insects, and the incipient heart of the higher animals; since the latter is never much prolonged, and speedily becomes doubled (as it were) upon itself; and its first division into distinct cavities is merely for the purpose of separating its *receiving* portion, or *auricle*, from its *propelling* portion, or *ventricle*. But the general *condition* of the Circulating system is much the same in the two cases; and it is further alike in this,—that it is not always easy to show that the vessels have distinct walls, as they frequently seem like mere channels excavated in the tissues.

555. We may next turn our attention briefly to the condition of the Circulating apparatus in the *Molluscous* classes, which has lately been found to present some very peculiar characters. In these it would seem as if the moving power were more concentrated in the heart, that in the preceding; for this organ seems no longer like a mere dilatation of the vascular trunk, but is a distinct sac with muscular walls, usually having at least two cavities, an auricle and a ventricle. The ordinary course of the Circulation is the following. The blood, expelled from the ventricle of the heart, passes along the main systemic artery, or aorta; which distributes it to

the body at large. It is then collected again, and transmitted to the respiratory organs; in which it is exposed, either to the air contained in the surrounding water, or (in the terrestrial Mollusks) more directly to the atmosphere; and from these it is returned to the heart, to be again transmitted to the system.—Thus we see that the heart of these animals receives and impels *aerated* blood; and that its office is, to send that blood to the capillaries of the general system. Hence it may be called a *systemic* heart.

556. The blood, in the first part of its course, passes through distinct vessels: it has been lately shown, however, that in the Mollusks in general, the blood which has passed through the systemic capillaries, and is on its way to the respiratory organs, is no longer thus confined, but that it meanders through passages or *lacunæ*, which are channelled-out in the tissues, wherein they even communicate freely with the abdominal cavity in which the viscera lie; so that their whole exterior is bathed by the circulating fluid. It is perhaps in this part of its course, that it most readily takes-up the fresh nutrient materials which have been prepared by the digestive process, and which would under such circumstances find their way with comparative facility from the inner surface of their walls to the outer.—After being thus diffused, in its venous or carbonized state, through the substance of the tissues and through the visceral cavity, it is again collected into distinct trunks; and these convey it to the respiratory organs.—Now although it cannot be doubted that the impelling power of the heart is the chief cause of the movement of the blood through the systemic vessels, yet it would seem impossible to suppose that this power can be exerted over the unrestrained currents in which it is diffused through the body, after passing through the systemic capillaries; and it can scarcely be doubted that its passage through the capillaries of the respiratory organs, is due to the power which is developed in themselves, under the conditions already alluded-to.

557. There is a very curious phenomenon to be observed in the circulation of some of the lowest Mollusks; namely, the continual *reversal* of the course of the current. The heart, in these animals, is much less perfectly formed than in the higher tribes; and seems more like the mere contractile dilatation of the principal trunk, which is the sole representative of that organ in the Echinodermata. The circulating fluid is sometimes transmitted first to the system; after being distributed to its different parts by the ramifications of the main artery, it meanders through the channels excavated in the tissues; and it then flows towards the respiratory surface, after passing over which, it returns to the heart. But after a certain duration of its flow in this direction, the current stops, and then recommences in the contrary direction,—proceeding first to the respiratory organs, and then to the system in general. It would seem as if in this, one of the lowest forms of animals possessing a

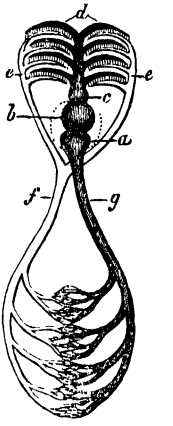
distinct Circulation, the central power were not yet sufficiently strong to determine the course which the fluid is to take, so that it undergoes continual vacillations. In a group of Compound Polypes to which this class of Mollusks has many points of resemblance, there is a movement of fluid through the stem and branches, which continually changes its direction in like manner. This movement, however, can scarcely be regarded in the light of a proper Circulation; since the tubes in which it occurs are in direct communication with the digestive cavities of the Polypes. But the flow seems altogether independent of any mechanical propulsion; and takes-place most energetically and regularly towards parts in which new growth is going-on.

558. We have now to consider the chief forms in which the Circulating apparatus presents itself in the Vertebrated classes; and first in that of *Fishes* (Fig. 95). We have here, as in Mollusks, a heart with two cavities, an auricle and a ventricle; this heart, however, is not placed at the commencement of the systemic circulation, but at the origin of the respiratory vessels. The blood which it receives and propels, is venous or carbonized; this is transmitted along a main trunk, which speedily subdivides into lateral branches or arches; and these distribute it to the fringes of gills that hang on the sides of the neck. By the action of the water on the gills, the blood is aerated in its passage through them; and it is then collected by a series of converging vessels, which reunite to form the great systemic artery or aorta. By the ramifications of this artery, the blood, now aerated, is distributed through the system, and affords the requisite nourishment and stimulation to its tissues. Returning from the systemic capillaries in a venous state, the blood of the head and anterior portion of the body finds its way at once into the great systemic vein, or vena cava, by which it is conveyed back to the auricle of the heart; but that which has traversed the capillaries of the posterior part of the body and of the abdominal viscera, is conveyed by a distinct system of veins to the liver and the kidneys. In these organs, the veins again subdivide into a network of capillaries, which is distributed through the secreting structure, and which affords to the secreting cells the materials of their development. This is termed the *portal* system of vessels. From the capillaries of the liver and kidneys, the blood is finally collected by the hepatic and renal veins, which convey it into the vena cava; where it is mingled with the blood that has not passed through those organs, and is conveyed with it to the heart.

559. The heart of Fishes, then, belongs to the *respiratory* circulation. It propels venous blood to the capillaries of the gills, in which it is aerated; returning from these, the aerated blood is transmitted through a second set of capillaries, those of the system, in which it again becomes venous; whilst a portion of this blood is

made to traverse a third set of capillaries, those of the liver and kidneys, before it is again subjected to the propelling power of the heart. Now as the heart, instead of being stronger than it is in animals with the complete double circulation presently to be described (§ 564),—in which the greater part of the blood propelled by the central organ only traverses one set of capillaries, and never more than two,—is much weaker in proportion, it is evident that here, too, a supplementary power must exist, by which the flow of blood through the capillaries is aided, and on which, indeed, the portal circulation must greatly depend.

Fig. 95.*



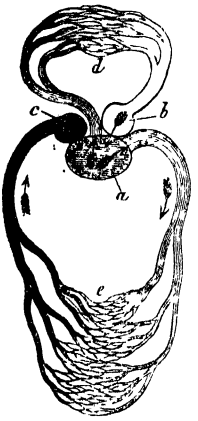
560. An extremely interesting aspect of the circulating apparatus is presented by the *Amphioxus* or Lancelet; an animal which possesses the general form of a Fish, and which can scarcely be referred to any other group; but in which the characters of the Vertebrated series are degraded (as it were) to the level of the lower Molluscous and Vermiform classes. The blood, which is white, moves through distinct vessels, but there is no proper heart; and the vascular trunks present several dilatations in different parts, which have muscular walls and show contractile power. Thus the circulation is carried-on, not through the agency of a central impelling organ, as in other Fishes; but by a power which is scattered or diffused through various parts of the system of blood-vessels, as in the lower Invertebrata.—The respiratory apparatus, also, is formed upon a type much lower than that of Fishes; for it consists simply of a dilatation of the first part of the alimentary canal, or pharynx, upon the walls of which the blood is distributed in divided streams, its cavity being filled with water, which serves to aerate the blood. This is precisely the type on which the respiration is effected, in those lowest Mollusks of which mention has just been made as exhibiting alternations in the direction of the circulating current (§ 557). In other respects, however, the arrangement of the vascular system in this extraordinary animal corresponds with that which obtains in Fishes.

561. It is requisite that, in the class of Fishes, the *whole* of the

* Diagram of the Circulating Apparatus of *Fishes*:—*a*, the auricle; *b*, the ventricle; *c*, the trunk supplying the branchial arteries, *d*; the aerated blood returning from the gills is conveyed by *e*, *e*, the branchial veins, to *f*, the aorta, which distributes it to the system; thence it is collected, and returned to the auricle, by the veins which unite in the vena cava, *g*.

venous blood returned from the system should pass through the respiratory organs, before being again transmitted to the body; since the aerating action of the small quantity of air diffused through the water, would otherwise be insufficient for its renovation. But in *Reptiles*, all of which breathe air during their adult condition, the case is very different; for if the whole current of their blood were exposed to the atmosphere, before being again sent to the body, the quantity of oxygen conveyed into the tissues would be too great, and would have an over-stimulating effect. The plan of Circulation is, therefore, differently arranged in Reptiles (Fig. 96). We find the heart to consist of three cavities; two auricles, and one ventricle. From the ventricle issues a single trunk, which speedily subdivides; some of its branches proceeding to the lungs, and others to the body. The blood which is transmitted through this trunk, is of a mixed character, as we shall presently see; being neither fully aerated, nor yet highly carbonized. It contains sufficient oxygen to stimulate the nervous and muscular systems of these comparatively inert animals; whilst it also contains enough of carbonic acid to require being exposed to the atmosphere through the medium of the lungs. The blood which has passed through the systemic capillaries, and which has been thereby rendered completely venous, is returned by the vena cava to one of the auricles —the systemic. On the other hand, the blood which has passed through the capillaries of the lungs, and which has been thereby rendered completely arterial, is returned through the pulmonary vein to the other auricle,—the pulmonary. Thus one of the auricles exclusively receives oxygenated, and the other carbonated blood; and as both pour their contents into the common ventricle, the blood which that cavity contains and propels is of a mixed character.

Fig. 96.*



562. Various modifications of this form of Circulating apparatus exist in the different groups of Reptiles. In the lowest among them (the perennibranchiate Amphibia), which breathe permanently

* Diagram of the Circulation in *Reptiles*.—*a*, single ventricle, receiving aerated blood from *b*, the pulmonary auricle, and venous blood from *c*, the systemic auricle; and propelling part of this mixed fluid to the pulmonary capillaries, *d*, and part to the systemic capillaries, *e*.

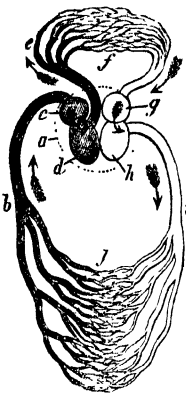
by gills like Fishes, besides possessing imperfectly-developed lungs, the apparatus exhibits a blending of both plans; for a small portion of the blood which is propelled by each contraction of the ventricle, passes directly to the lungs; the principal part of it being at once distributed to the gills, as in Fishes. After passing through these, it is transmitted to the general system; and on returning thence in a completely venous state, it is mingled with the blood which has been arterialized in the lungs. This latter, however, bears so small a proportion to the rest, that, if the aeration were not partly effected by the gills, it would be insufficient for the wants of the animal.—The tadpoles of the common Frog and Water-newt, as well as of other species which, like them, begin life in the general condition of Fish, present a similar condition at one period of their change. At first the whole aeration is effected by means of gills, the lungs being in a rudimentary or undeveloped state; and the entire circulation is carried-on as in Fishes, the pulmonary vessels being scarcely traceable. As the lungs begin to be developed, however, a portion of the blood is sent to them; and at the same time, communicating passages which previously existed between the vessels that convey blood to the gills and those that return it from them, are increased in size; so that a certain proportion of the blood is transmitted to the system, without having passed through the gills at all. By a further increase in the diameter of these, the whole current of blood takes this direction, the gills being no longer serviceable; and as, at the same time, the lungs are attaining their full development, the aeration which they effect in the blood transmitted to them becomes sufficient, and the whole circulation is thus permanently established on the Reptilian type.

563. On the other hand, among the higher Reptiles, we find the circulating apparatus presenting approaches to the form it possesses in Birds and Mammals. For the ventricle is divided, more or less completely, into two cavities, one of which propels aerated blood to the system, whilst the other transmits venous blood to the lungs. A certain amount of mixture of arterial and venous blood always takes-place, however, either in the heart itself, or in the vessels; so that the blood which the body receives is never purely arterial. But this mixture is sometimes effected in such a manner, that pure arterial blood is sent to the head and anterior extremities; though the remainder of the body receives a half-aerated fluid. This is accomplished in the Crocodile, by a provision very similar to that which exists in the fœtus of warm-blooded animals (CHAP. XI.). The *portal* circulation in Reptiles is carried-on nearly upon the same plan as in Fishes. It receives the blood from the posterior extremities and from the tail, as well as from the abdominal viscera; and this blood is distributed by the portal capillaries, not only through the liver, but also through the kidneys, although the

latter also receive arterial branches from the aorta. The fact that the kidneys are supplied from the general portal circulation in Fishes and Reptiles, has an important bearing on the difference which will be hereafter shown to exist in the arrangement of the vessels, between the kidneys of these animals and those of Birds and Mammals (§ 728).

564. In the warm-blooded division of the Vertebrated series, which includes the classes of Birds and Mammals, we find the whole circulation possessed of a greatly-increased energy; but the distinguishing peculiarity of the apparatus in these animals, is that conformation of the heart and vessels which secures a *complete double circulation* of the blood; that is, which provides for the aeration of every particle of the venous blood that has returned from the system, before it is again sent into the tissues. The heart may be regarded as consisting of two distinct parts,—a *systemic* heart, like that of the Mollusks, forming its left side,—and a *respiratory* heart, like that of Fishes, constituting its right (Fig. 97). Each of these parts has a receiving cavity or auricle, and an impelling cavity or ventricle. The cavities of the two sides are completely separated from one another, in the adult state at least; though their walls are united, for economy of material. It is obvious that much is saved in this manner; since, as the contractions of the auricles and of the ventricles on the two sides occur simultaneously, the pressure of blood in the one is partly antagonized by that on the other, so far as it acts on the wall that is common to both. This antagonism is not complete, however, since the systemic ventricle contracts with far greater force than the pulmonary; and the wall between them must be capable of resisting the difference of pressure on its two sides, thus occasioned.—The blood which is returned from the system, in a venous state, through the vena cava to the right auricle,

*Fig. 97.**

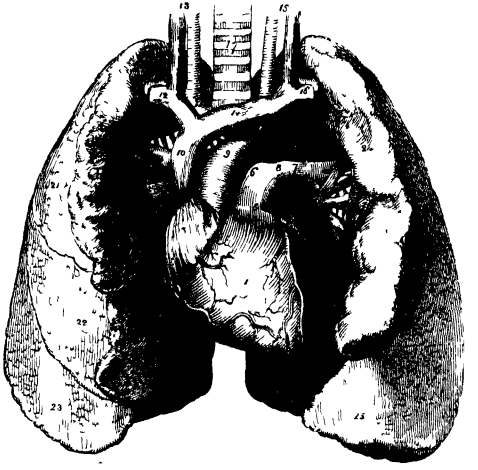


* Diagram of the Circulating Apparatus in *Mammals* and *Birds*:—*a*, the heart, containing four cavities; *b*, vena cava, delivering venous blood into *c*, the right auricle; *d*, the right ventricle, propelling venous blood through *e*, the pulmonary artery, to *f*, the capillaries of the lungs; *g*, the left auricle, receiving the aerated blood from the pulmonary vein, and delivering it to the left ventricle, *h*, which propels it, through the aorta, *i*, to the systemic capillaries, *j*, whence it is collected by the veins, and carried back to the heart through the vena cava, *b*.

and which is poured by it into the right ventricle, is impelled by the latter through the capillaries of the lungs, where it undergoes aeration. Returning thence, in an arterialized state, it is conveyed into the left auricle, and thence flows into the left ventricle; by which it is propelled through the great systemic artery or aorta, and through its ramifications to the general system.

565. The greater part of the blood which has been rendered venous by passing through the systemic capillaries, is collected by the systemic veins, and is returned directly to the heart through the vena cava. But a portion is still employed for that distinct circulation

Fig. 98.*



* Anatomy of the Human Heart and Lungs:—1. the right ventricle; the vessels to the right of the figure are the middle coronary artery and veins; and those to its left, the anterior coronary artery and veins; 2. the left ventricle; 3 the right auricle; 4 the left auricle; 5. the pulmonary artery; 6. the right pulmonary artery; 7. the left pulmonary artery; 8. the remains of the ductus arteriosus; 9 the arch of the aorta; 10. the superior vena cava; 11. the right arteria innominata, and in front of it the vena innominata; 12. the right subclavian vein, and behind it its corresponding artery; 13. the right common carotid artery and vein; 14. the left vena innominata; 15. the left carotid artery and vein; 16. the left subclavian vein and artery; 17. the trachea; 18. the right bronchus; 19. the left bronchus; 20, 20. the pulmonary veins; 21. the superior lobe of the right lung; 22. its middle lobe; 23. its inferior lobe; 24. the superior lobe of the left lung; 25. its inferior lobe.

which is destined to supply the materials for the secreting action of the liver. The blood that has traversed the capillaries of the walls of the alimentary canal, and of the other viscera concerned in digestion, is collected again by the converging veins into a large venous trunk, the *vena portæ*, by which it is distributed through the liver. This vessel, although formed by the convergence of veins, and conveying venous blood, has really the character of an artery in an equal degree; for it subdivides and ramifies after its entrance into the liver, so as to form a network of capillaries, from which the blood is again collected, and thence transmitted by the hepatic vein to the vena cava.—Thus that portion of blood which supplies the liver with the materials of its secreting action, passes through two sets of capillaries, between the time of its leaving the heart and its return to it. The portal circulation in Birds, as in Reptiles and Fishes, receives the blood from the posterior part of the body, and from the extremities; but the portal blood is only conveyed to the liver; the kidneys being supplied by the renal artery.

566. This perfect form of the Circulating apparatus is only attained, in the warm-blooded animal, after a series of transformations which strongly remind us of the permanent forms presented by the vascular system in Fishes and Reptiles. Thus in the embryo of the Chick at about the 60th hour, and in that of the Dog at about the 21st day, the curved and dilated tube of which the heart previously consisted (§ 554), is found to be distinctly divided into an auricle and a ventricle. From the latter originates the main arterial trunk, which divides into four pairs of lateral branches; and these pass round the pharynx, precisely in the position and direction of the arteries of the gills of Fishes. They do not, however, distribute the blood to gill-tufts, for none such are developed in the embryo of the warm-blooded animal; but they meet again below the pharynx, to form a trunk which supplies the general circulation.—Within a short period, however, the whole plan of the circulation undergoes a change. The auricle and the ventricle are each divided by a partition that is developed in the middle of the heart; and thus the two auricles and the two ventricles are formed. Whilst this is going-on, a change takes-place also in the vessels that arise from the heart; for the arterial trunk that was previously single, undergoes a division into two distinct tubes; one of which is connected with the left ventricle and becomes the aorta, whilst the other originates in the right ventricle and becomes the pulmonary artery. Of the four pairs of branchial arches, some are subsequently obliterated; whilst others undergo changes that end in their becoming the arch of the aorta, the right and left pulmonary arteries, and the right and left subclavians.

567. The muscular power of the heart is much greater in the warm-blooded than in the cold-blooded Vertebrata, in proportion to

the extent of the circulation which it is concerned in maintaining; and it is evidently destined to take a much larger share in the propulsion of the fluid, than it is in the lower tribes. Many Physiologists, indeed, are of opinion that the movement of the blood is *entirely* due to the action of the heart; and this view appears to be supported by the results of numerous experiments upon the circulation. But it is very difficult, if not impossible, to make experiments that shall be really satisfactory upon this point; and it appears safer to trust to the "experiments ready prepared for us by Nature," as Cuvier termed them,—namely, those lower forms of animated being, in which various diversities of structure present themselves, and in which we can study the regular and undisturbed effects of these. Thus we have seen that, in Plants and the lowest Animals, which have no central impelling cavity, the movement of the nutritive fluid is entirely dependent upon the power that is diffused through the network of vessels in which it circulates. As we ascend the series, we find an organ of impulsion developed upon a certain part of the vascular system, whose object it is to give increased energy and regularity to the movement. And ascending still higher, we find the moving power gradually concentrated, as it were, in this organ; yet it is not altogether withdrawn from the capillary network, as we shall see from several facts to be presently adduced. The particular actions of the Heart, the Arteries, the Capillaries, and the Veins, will now be considered in more detail.

3. *Action of the Heart.*

568. The Heart is a hollow muscle, endowed in an eminent degree with the property of *irritability;* by which is meant, the capability of being easily excited to movements of contraction alternating with relaxation (§ 347). At first sight its actions seem different from those of the muscles which are called into action by the impulse of the will; for in these there is apparently no such alternation, the state of contraction being kept-up as long as the will operates. But it has been already explained that, even in these, the individual fibres are probably in a state of continual alternation of contraction and relaxation, during their active condition,—one set taking-up the action, whilst another is returning to the state of relaxation. Hence the chief peculiarity in the Heart's action consists in this,—that the whole mass of fibres of each division of the organ contract and relax *together.* The contraction of the two ventricles is perfectly synchronous, as is that of the two auricles; but the contraction of the auricles is synchronous with the dilatation of the ventricles, and *vice versâ.* The regularity of this alternation, however, is somewhat disturbed when the irritability of the heart is becoming exhausted; and both sets of movements will continue, when the auricle and ventricle have been

separated from one another. Their regular succession, in the natural state, is doubtless in part due to the fact, that the transmission of blood from the auricle into the ventricle, by the contraction of the former, is the stimulus which most effectually excites the latter to contraction; whilst the ventricle is contracting, the auricle, now free to dilate, is distended by the flow of blood from the veins that open into it; and this flow stimulates it to renewed contraction, just at the time when the contraction of the ventricle has been completed, and *its* state of relaxation enables it to receive the blood poured-in through the orifice leading from the auricles.

569. In the living animal, the auricular and ventricular movements succeed one another with great regularity; and, when the circulation is proceeding with vigour, scarcely any appreciable pause can be discovered between the different acts. The contraction or *systole* of the Auricles occupies only about one-eighth of the entire period that intervenes between one pulsation and another, the diastole occupying the remaining seven-eighths. The systole and diastole of the Ventricles on the other hand, divide the entire period equally between them. The systole of the Ventricles occasions the propulsion of blood into the arterial system; and this action produces the *pulse*, as will be explained hereafter (§ 583). And it also corresponds with the *impulse* or stroke of the heart against the parietes of the chest. This impulse is produced, not, as some have supposed, by the swinging of the entire heart forwards; but by the peculiar mode in which the Ventricular systole takes-place. In the contraction of its walls, every dimension is lessened; but *shortening* is the most perceptible change, the vertical diameter of the Ventricle being the greatest. Owing to the peculiar spiral disposition of the fibres of the heart, its apex is not simply drawn upwards by their contraction, but it is made to describe a spiral movement, from right to left, and from behind forwards; and it is in this manner that it is caused to strike against the side of the chest.

570. The systole of the Ventricles is immediately followed by their diastole; but during the earlier part of this, the Auricles are still dilating, the blood being poured into them by the great veins faster than it passes from them into the Ventricle. And thus the Ventricular diastole may be divided into two stages; the *first* seeming due to the simple elasticity of the walls of the Ventricles, whilst in the *second*, which is accompanied by the systole of the Auricles, the blood of the latter is forcibly propelled into them. When the circulation is being carried-on regularly, the blood is propelled into the Ventricles with sufficient force to dilate them strongly; so that the hand closed upon the heart is opened with violence. Even the auricles dilate with more force than it seems easy to account-for by the *vis a tergo* of the blood in the venous system, which is small compared with that which the fluid possesses in the arteries. A to

571. The natural movements of the Heart are accompanied by certain Sounds, which are heard when the ear is applied over the cardiac region; and an acquaintance with these sounds and with their causes is of much importance, since the alterations which they undergo in disease, afford us some of our most accurate information in regard to the nature of the morbid affection. Concurrently with the *impulse* of the heart against the chest, a dull and prolonged *sound* is heard; this, which is termed the *first* sound, marks the ventricular systole, and is synchronous with the pulsation in the arteries. The second sound, which is short and sharp, follows *immediately* upon the conclusion of the first; and it must therefore be produced during the first stage of the Ventricular diastole, before the systole of the Auricles has commenced. It is followed by a brief interval of repose, which occurs during the remainder of the Ventricular diastole and the Auricular systole; and this is succeeded by a recurrence of the first sound. If the whole period between two successive pulsations be divided into four parts, it is estimated by Volkmann that the two sounds together occupy two of these, and that the interval occupies the remainder.

572. Now in order to understand the causes of these sounds, it is necessary to study the course of the blood through the heart a little more in detail. When the Ventricles, distended with blood, are contracting upon their contents, they eject them forcibly through the narrow orifices of the aorta and pulmonary artery; and the semilunar valves which guard these orifices, are thrown-back against the walls of the arteries. The regurgitation of the blood into the auricles is prevented by the action of the mitral and tricuspid valves; but the flaps of these do not suddenly fall against each other, when the blood first begins to press them together; being restrained by the *chordæ tendineæ*. The connection of these with the *carneæ columnæ*, which form part of the ventricular walls, and contract simultaneously with them, appears to have this use; —that the flaps of the valves, which are completely thrown back during the preceding rush of blood from the auricles to the ventricles, may be drawn into a favourable position for the blood to get behind them and bring them together, so as completely to close the orifice. As soon as the ventricular diastole begins to take place (even before the contraction of the auricles has commenced), there will be a tendency of the blood that has just been propelled into the aorta and pulmonary artery, to flow back to the heart; but this regurgitation is completely prevented by the semilunar valves of these orifices, which are immediately filled-out by the backward tendency of the blood, and which meet in such a manner as completely to close the orifices. This closure is much more sudden than that of the mitral and tricuspid valves, being altogether unrestrained.

573. The *first* sound is certainly *in part* due to the impulse of

the heart against the thoracic parietes; as is proved by the fact, that, when the impulse is prevented, the sound is much diminished in intensity; and also by the circumstance, that, when the ventricles contract with vigour, the greatest intensity of the sound is over the point of percussion. But that it is *not entirely* due to this cause, is also sufficiently evident from two circumstances;—its prolonged character, which could scarcely be given by a momentary impulse;—and its continuance, though with diminished intensity, when the parietes of the chest are wanting, and even after the complete removal of the heart from the body. Moreover, the duration of the first sound is much increased by any morbid state of the orifices of the ventricles which obstructs the exit of the blood. Much discussion has taken-place as to the cause of that part of it which is not due to the impulse; some having attributed it to the muscular contraction of the walls of the ventricles, others to the flow of blood over the irregular surfaces of their interior, and others to the rush of the fluid through the narrow orifices leading to the aorta and pulmonary artery. There can be little doubt, that the first and last of these causes are both concerned in producing the sound. For as a sound may be distinctly heard by means of the stethoscope, when the heart is contracting vigorously out of the body, and when no blood is propelled by it, nothing else than muscular contraction can be then regarded as its source; and there is other evidence that sound may be produced by this cause, since the vigorous contraction of any other large muscle gives-rise to a continued tingling, which may be heard through the stethoscope. But when the heart is contracting in its natural position, and is propelling the blood with its ordinary vigour, the sound is heard in its greatest intensity at the *base* of the heart, *i. e.*, at the origin of the great arteries; and since any obstruction to the exit of the blood through them increases the intensity as well as the length of the sound, it can scarcely be doubted that it is partly due to the rush of the blood through the contracted entrances of these vessels. A very similar sound, known as the 'bruit de soufflet' or bellows-sound, may be heard through the stethoscope, over any large artery, when it is so compressed as to permit the passage of blood less readily than usual. Thus the ordinary first sound may be regarded as composite in its nature; being made-up of the sound produced by the impulse of the heart against the parietes of the chest, of the muscular sound occasioned by the forcible contraction of the thick walls of the ventricles, and of the sound generated by the friction of the particles of blood against each other and against the boundaries of the narrowing orifices which lead into the vessels.

574. The cause of the *second* sound is simpler and more easily understood. It is due to the sudden filling-out of the semilunar valves with blood, at the moment when the ventricular systole has

ceased, and when the commencing diastole produces a tendency to the regurgitation of blood from the aorta and pulmonary artery. The sudden passage of the valves, from a state of complete relaxation to one of complete tension, occasions a sort of *click;* which is the second sound of the heart. That this is the real cause, has now been fully demonstrated. If one of the valves be hooked-back against the side of the artery, by the introduction of a curved needle, so that a reflux of blood is permitted, the sound is entirely suppressed. And if the complete closure of the valves be prevented by disease, so that their tension is diminished, and a certain amount of regurgitation takes-place, the second sound is no longer heard in its proper intensity; whilst, on the other hand, a sound analogous to the first, and sometimes prolonged over the whole interval of repose, indicates the reflux of the blood into the ventricles. When the semilunar valves are thickened by morbid deposit, their surface roughened, and their opening narrowed, the *first* sound becomes harsher and sharper; and the *second* sound acquires the same character,—the backward as well as the forward flow of the blood being affected by this cause.

575. The natural movements of the mitral and tricuspid valves appear to be accomplished with perfect freedom from sound; for the size of the orifices which they guard prevents any considerable friction of the blood, in its flow from one cavity to the other; and their closure when the ventricular systole begins, does not take place with the rapidity and suddenness of that of the semilunar valves. But when their structure is changed by disease, their action is not so noiseless; and they give rise to various morbid sounds, which are heard in addition to the ordinary sounds, and which may even obscure them altogether.—In the same manner, the ordinary movements of the heart do not produce any audible friction-sound between the two surfaces of the pericardium, that which covers the heart, and that which lines the pericardial sac. These surfaces are kept moist, in health, by the serous fluid constantly exhaling from them; and they are extremely smooth, so that they glide over one another noiselessly. But if they become dry, as in the first stage of inflammation, a slight creaking is heard, accompanying *both* the ordinary sounds of the heart, and somewhat resembling the rustling of paper. And if they be roughened by the deposit of inflammatory exudations, this 'to and fro' sound becomes of a harsher character.

576. The walls of the left ventricle are considerably thicker than those of the right; and their contractile power is greater. This difference is obviously required by the difference in length between the systemic and the pulmonary vessels; the amount of force necessary to drive the blood through the latter, being far inferior to that which is requisite to propel it through the former. The average thickness of the walls of the *left* Ventricle is about 4½ lines; being

somewhat greater than this at the middle of the heart, and less at its apex. The average thickness of the walls of the *right* ventricle is not more than 1½ line; being a little greater than this at the base, and less at the apex of the heart. The left auricle is somewhat thicker than the right.—The capacities of all the four cavities are nearly equal; each of them, in their state of most complete dilatation, holding about three ounces of fluid. The Ventricles are, perhaps, a little larger than their respective Auricles; but there is no very positive difference in capacity between the Ventricles and Auricles of the two sides.

577. The quantity of blood which is propelled at each Ventricular systole, cannot, therefore, exceed three ounces; and it is probably somewhat less, as the ventricles do not seem to empty themselves completely at each contraction. Now the whole quantity of the blood seems to be about one-eighth of the entire weight of the body; so that it will amount to about 18 lbs. in an individual of 144 lbs. weight. Allowing 72 pulsations to a minute, 216 oz. (or 13 lbs. 8 oz.) of blood would pass through each ventricle of the heart in that time; consequently about eighty seconds would be required for the passage of the entire mass of the blood through the whole circle of its movement, if its rate be entirely determined by the impulses it receives from this central organ.—But it appears, from various experiments, that the rate of circulation is much more rapid than this. For if a solution of any salt easily detectible in the blood, be injected into one of the large veins near the heart, it may be traced in the arterial circulation in from 15 to 20 seconds afterwards; during which interval it must have traversed the whole pulmonary system of vessels, and passed through both sides of the heart. And if the salt be one which acts powerfully on the heart itself,—as is the case with Nitrate of Baryta or Nitrate of Potass,—this action is manifested almost at the same moment with the appearance of the salt in the arteries of other parts; thus showing that it has been conveyed by the coronary arteries into the capillaries of the cardiac tissue. The period required for the transmission of the saline substance from the veins of the upper part of the body to those of the lower,—which can scarcely be accomplished through any more direct channel than the current that returns to the heart, then passes through the lungs back to the heart again, and then flows through the systemic arteries and capillaries to the veins,—is accomplished in little more than 20 seconds, even in an animal so large as a Horse. It appears, then, that even the vigorous and constant action of the Heart is not alone sufficient to maintain the circulation at its ordinary rate; and we are not justified, therefore, in excluding those sources of movement in the higher animals, which evidently exert so important an influence in the lower.

578. The force with which the heart propels the blood is such,

that if a vertical pipe be inserted into the Carotid artery of a horse, the blood will sometimes rise in it to a height of 10 feet. From comparative experiments upon other animals, it has been estimated that the vigorous action of the heart in Man would sustain a column of blood in his aorta about 7½ feet high; or, in other words, that the force with which the heart ordinarily propels the blood through the aorta, is equal to that which would be generated by the weight of a column of blood of the same size, and 7½ feet high; which weight would be about 4⅓ lbs. But the force which must be exerted by the heart to sustain such a column, may be shown, upon physical principles, to be as much greater than this, as the area of a plane passing through the base and apex of the left ventricle is greater than that of the transverse section of the aorta; and since the proportion of these areæ is about 3 : 1, the real force of the heart may be stated at about 13 lbs.

579. The number of contractions of the heart, in a given time, is liable to great variations within the limits of health, from several causes; the chief of which are diversities of Age and Sex, amount of Muscular exertion, the condition of the Mind, the state of the Digestive system, and the period of the Day.—The following are the points of greatest importance, in regard to the action of these several influences.

Age.—The pulse of the newly-born infant averages from 130 to 140 per minute; and this rate gradually diminishes, until, in adult age, the pulse averages from 70 to 80; and in the decline of life from 50 to 65.

Sex.—The pulse of the adult female exceeds that of the adult male in frequency, by about 10 or 12 beats in a minute; and it is also more liable to disturbance from other causes.

Muscular Exertion.—The effect of this in accelerating the pulse is well known; but as the amount of change depends upon the degree of exertion, no general statement can be made on the subject. The continued influence of a moderate degree of muscular exertion, is shown by the effect of *posture* upon the pulse. Thus the pulse is on the average from 7 to 10 beats faster (per minute) in the standing than in the sitting posture; and 4 or 5 beats faster in the sitting than in the recumbent posture. This amount of variation is temporarily increased by the muscular effort required for the *change* of posture; but this soon subsides into the continued rate which the permanent maintenance of the new posture involves. There are certain states of the system, in which the heart's action is increased to a most violent degree by a simple change of posture; and in which, therefore, it is necessary that even this slight movement should be made with gentleness and caution.

Mental Condition.—The action of the heart is peculiarly influenced, as every one is aware, by the excitement of the *emotions.*

This is a fact to which, however familiar, the medical practitioner should constantly direct his attention. The trifling agitation occasioned by the entrance of the medical man will produce, in many patients, such an acceleration of the pulse, as would be very alarming, if its true cause were not known. And the real rate of the pulse cannot be ascertained, until time has been permitted for the agitation to subside; which is favoured, also, by the influence of a gentle manner and tranquillizing conversation. The operation of the *intellectual* powers does not seem to affect the rate of the heart's movement in any other way, than by inducing a general state of feverishness, if it be too long or too energetically kept up.

State of the Digestive System.—The pulse is quickened during the digestion of a meal; but no exact numerical statement can be made on this subject.

Period of the Day.—The frequency of the pulse appears to be somewhat greater in the morning than it is in the evening; and the temporary action of any of the preceding causes more quickly subsides in the evening than in the morning.

580. The movements of the Heart have been supposed to depend upon a constant supply of nervous influence, generated by the cerebro-spinal system, and transmitted through the sympathetic nerve, the branches of which are copiously distributed to it. And this idea seemed to derive support from the fact, that, when the brain and spinal cord are removed, or when large portions of them are suddenly destroyed, by crushing or by the breaking-up of their substance in any other mode, the movements of the heart are arrested. But it has been shown that the brain and spinal cord may be *gradually* removed, without any such consequence; and the occasional production of fœtuses destitute of those centres, but possessed of a regularly-pulsating heart, is another proof that the movements of this organ do not *depend* upon a supply of nervous influence derived from them. Still they are capable of being influenced by impressions transmitted through the nerves. It has been ascertained by Valentin, that, after the heart has ceased to beat, its contractions may be re-excited by stimulating the roots of the Spinal Accessory nerve, or of the first four Cervical nerves; the influence of that stimulation being conveyed to the heart by the Sympathetic system, the cardiac portion of which communicates with these nerves. Irritation of the Par Vagum, also, has a tendency to accelerate the heart's action, or to re-excite it when it has ceased; but the complete severance of both its trunks produces little disturbance in the regularity of the movement. The action of the heart may be also affected more directly through the Sympathetic system; thus it is excited by irritation of the cervical ganglia, especially the first; whilst continued pressure upon the cardiac nerve, by an enlarged bronchial gland, has appeared to be the cause

of its occasional suspension. It is without doubt through its nervous connections, and probably through the sympathetic system, that the heart receives the influence of mental emotions.

581. The movements of the heart may be suspended or altogether checked, by sudden and violent impressions on the nervous centres, even though these do not occasion any perceptible breach of substance. Thus in *concussion* of the brain, there is not merely insensibility, but also a complete suspension of the circulation, occasioned by a failure of the heart's power. This suspension may be permanent, so that animation cannot be restored; or it may be temporary, as in ordinary fainting. The well-known influence of blows upon the epigastrium, in producing sudden death, is probably to be attributed to a similar cause,—namely, the shock thus communicated to the extensive plexus of ganglionic nerves, radiating from the semilunar ganglia, and proceeding to the abdominal viscera. Violent impressions upon other nervous expansions may produce a dangerous weakening of the heart's contractile power; this is the case, for example, with extensive burns, which may produce faintness, and even death, especially in children, by the depression which they induce. Many other causes of sudden suspension of the heart's action might be enumerated; but they may be generally traced to a strong impression upon the nervous system; though of the mode in which this operates we know nothing.

4. *Movement of the Blood in the Arteries.*

582. The Blood propelled from the Heart into the Arteries by a series of interrupted jets, would continue to flow in the same manner, if it were not for the equalization of its movement effected by the properties of the arterial walls. This influence is exerted by the middle or fibrous coat, which consists in part of yellow elastic tissue (§ 190), and in part of non-striated muscular fibre (§ 337). The proportion of these two components varies in arteries of different calibre; the muscular tissue being thicker in the smaller branches, and the elastic tissue being found in larger amount in the main trunks.

583. It is chiefly to the simple physical property of *Elasticity*, thus possessed by the Arterial tubes, that we owe the equalization of the flow of blood; and we may hence understand the reason why the trunks that are in nearest connection with the heart, should be those most endowed with it. If a forcing-pump were to inject water, by successive strokes, into a system of tubes with perfectly unyielding walls, the flow of fluid at the farther extremities of these tubes would be as much interrupted as its entrance into them. But if the pump be connected with an air-vessel (as in the common fire-engine), so that a part of the force of each stroke is expended in compressing the air, the expansion of this, during the

interval between the successive strokes, produces a continuous flow of water along the tubes. Or if the tubes themselves were endowed with a certain degree of elasticity, which should allow them to dilate near their commencement, so as to receive the new charge of fluid, and which should occasion a continued pressure upon the fluid during the intervals of the stroke, the same equalizing effect would be produced. This is precisely the case with the Arterial system; the intermittent jets by which the blood is propelled from the heart, are speedily converted into a continued stream; so that, at even a moderate distance from the heart, the only indication of its interrupted action is presented by the greater or less rapidity of the flow; and this gives rise, when an artery is divided, to an alternate rise and fall of the jet of blood, and, in the ordinary circulation, to the phenomenon called the *pulse*. This is due to an increase in the dimension of the arterial tube, both in length and breadth, with each additional increase of blood; the increase in length is the more considerable of the two effects, and causes the artery to be somewhat lifted from its seat. During the intervals, a quantity of blood corresponding to that which had entered, escapes by the further extremity of the tube; and thus the artery is enabled to contract to its previous dimensions, and to return to its bed. We may compare the pulse, therefore, to a wave, which commences in the heart, and travels onwards through the arterial system.

584. In the large arteries near the heart, the pulsation is always precisely synchronous with the ventricular systole; but it takes-place somewhat later in the arteries at a distance from the heart; the time required for the transmission of the wave being proportioned to the degree in which the walls of the arteries yield to it. If they were *quite* rigid, the egress at one extremity must take-place at the precise moment that the fluid is forced into the other. On the other hand, if the walls be too easily distensible, they yield to the propelling force in such a degree that it is entirely expended upon them; and the fluid is not moved onwards at all, or but very slowly. In the healthy state of the arterial walls, they should contract upon their contents with sufficient force to equalize the flow of blood, and to prevent the pulse-wave from occupying more than one-sixth or one-seventh of a second, in its propagation to the remotest arteries of the system; and the pulse should be full, producing a prolonged but gentle elevation beneath the finger, and capable of resisting moderate pressure. This condition is dependent in great part upon the due *tonicity* of the muscular coat of the arteries (§ 365). When this tonicity is in excess, the walls of the arteries are too rigid; the pulse at the wrist is felt to occur exactly at the same time with the ventricular systole; and its character is that of strength, incompressibility, and sustained power, though it may be even slower than usual. This is the case in what is commonly termed 'high condition' of the system, which

predisposes to inflammatory disorders, but which renders it less susceptible than usual to the influence of malaria, contagious miasmata, or other causes of a depressing character. On the other hand, when the tonicity of the arteries is less than it should be, their walls yield too much to the pulse-wave; so that the pulse at the wrist is often felt even after the *second* sound is heard, and the pulse itself is jerking, unsteady, and too easily compressible. This loose relaxed state of the vessels is the most unfavourable that can be to regularity and vigour of the circulation; and it manifests its ill effects in the general adynamic condition of the system, which is then peculiarly prone to suffer from the agency of malaria, infectious miasmata, or any other depressing causes.

585. Although many Physiologists have denied that the Arteries possess real Muscular Contractility in any degree, yet there can be no longer any doubt on the subject; since numerous experimenters have succeeded in producing distinct contraction in their walls, by the application of those stimuli which act upon muscular fibre in general. Moreover it has been ascertained that when an artery is dilated by the blood injected into it from the heart, it reacts with a force superior to the impulse to which it yielded; and that, if a portion of an artery from an animal recently dead, in which the vital properties are still preserved, and a similar portion from an animal that has been dead some days, in which nothing but the elasticity remains, be distended with equal force, the former contracts to a much greater degree than the latter, after the distending force is withdrawn.—One use of this contractile power may very probably be, to assist the Heart in maintaining the flow of blood; for if the Arterial walls yield readily to the ingress of blood, and then contract upon their contents with a force greater than that which distended them, the current must necessarily be propelled onwards with greater force. This supplementary propelling force, on the part of the arteries, may serve as a compensation to that diminution of the heart's power, which must result from the increased friction of the blood against the walls of the vessels occasioned by their subdivision; and we thus observe, even in the highest animals, some traces of that diffused agency, on which the Circulation is so much more dependent in the lower tribes.

586. It seems probable, however, that one chief use of the Muscularity of the Arterial walls, consists in its regulation of the diameter of the tubes, in accordance with the quantity of blood to be conducted through them to any part; the proper amount being determined by circumstances at the time. Such local changes may form a part of the regular series of actions of the human body, as when the Uterine and Mammary arteries undergo enlargement at the periods of pregnancy and parturition; and they occur still more frequently in diseases which are attended by increased action of particular organs. In such cases, it cannot be *vis a tergo* of the

Heart, that occasions the enlargement of certain arterial trunks, and of no others; since any increase in its propulsive power would affect all alike. It must be, therefore, through a power inherent in themselves, that the dilatation takes-place; and there seems much reason for attributing to the Sympathetic system of nerves a control over this power, and consequently the office of regulating the local distribution of blood, in accordance with the wants of the different parts. It is well known that the nerves of this system are copiously distributed upon the arterial walls; and they have been experimentally shown to possess the power of calling-forth contractions in their muscular tissue. Moreover there is every reason to believe, that the diameter of the Capillary blood-vessels, and the rate of the movement of blood through them, are much influenced by these nerves (§ 603); and it seems highly probable, therefore, that they should have a corresponding influence upon the size of the trunks from which these capillaries are derived.

587. The Arterial system possesses nearly the same relative capacity in every part; that is, if a section could be made through *all* the systemic arteries at a certain distance from the heart, the united areas would be found equal to that of the aorta; while those of the branches of the pulmonary arteries would equal those of their trunk. This results from the fact, that, at every subdivision, the united *areas* of the branches are almost precisely equal to that of the trunk from which they proceeded; although the united *diameters* of the former far exceed that of the latter. According to a well-known mathematical law, the areas of circles are as the squares of the diameters; consequently, in making such comparisons, it is necessary to square the diameters of the trunk and those of the branches, and to contrast the former with the sum of the latter. Thus a trunk whose diameter is 7, may subdivide into two branches, each having a diameter of nearly 5; for the square of 7 is 49, and twice the square of 5 is 50. Or a trunk whose diameter is 17 may subdivide into three branches, whose diameters are 10, 10, and 9½ (making 29½ as the sum of the *diameters*); for the square of the diameter of the trunk is 289, whilst the sum of the squares of those of the branches is 290¼. It appears, however, from Mr. Paget's admeasurements, that there is seldom an exact equality between the area of the trunk and that of its branches; the area sometimes increasing, and sometimes diminishing. The former seems the general rule in the upper extremities; the latter in the lower. Thus the area of the trunk of the external carotid is to that of its branches, as 100 to 119; whilst the area of the abdominal aorta, just before its final division, is to that of its branches as 100 to 89.

588. In almost every part of their course, the ramifications of the arteries communicate freely with each other by *anastomosis;* and this communication is most important, as affording the means by

which the circulation is sustained, when the current through the main trunk is obstructed. There is scarcely an artery in the body, except the aorta, which may not be tied, with the certainty that the blood will still be conducted to its destination by the collateral circulation. At first, the quantity which thus passes is very insignificant, and is by no means sufficient to supply what is needed; thus, when the femoral artery has been tied for popliteal aneurism, the limb becomes cold, and the sensibility of its surface and its muscular power are alike diminished. In a few hours, however, its warmth returns, and its sensibility and muscular power are restored; indicating that its circulation has been already re-established through the collateral branches. And where an opportunity presents itself at a subsequent period for examining the state of the vessels in such a limb, it is found that an extraordinary enlargement has taken-place in arteries that were previously of insignificant size, which form a communication between the branches that issue above and below the interruption. Moreover, it is commonly found that the main trunk has become completely impervious above the part where it was obliterated by the ligature, up to the point at which the nearest lateral branch is given-off.—Even the abdominal aorta has been tied in dogs, without fatal results; the circulation in the posterior part of the body and in the hinder extremities, being then maintained chiefly by the inosculation of the external mammary artery with the epigastric, upon the parietes of the abdomen.

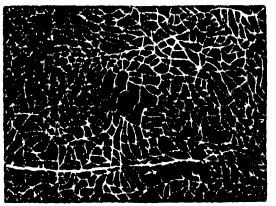
5. *Movement of Blood in the Capillaries.*

589. The ultimate ramifications of the Arteries pass so insensibly into those of the Veins, that no definite line of demarcation between them can be drawn; and although we are in the habit of speaking of the 'Capillaries' as a distinct system of vessels, yet it ought to be strictly borne in mind, that they differ only in size from the vessels from which they receive their blood on the one side, and into which they pour it on the other. It was at one time supposed that they are merely channels or passages excavated in the tissues, having no definite walls of their own. This is probably true of them in the lower tribes of Animals; and it may also be the case at an early stage of their development in the higher. But when their formation is complete, they undoubtedly possess walls of a fibrous texture, as distinct as those of the arteries and veins, though of extreme thinness. From the occasional appearance of bodies resembling cell-nuclei in the substance of the walls of the capillaries, it has been thought that their tubes are formed, in the first instance, by the coalescence of cells arranged in a linear direction; and this idea receives confirmation from the fact, that the ducts of Plants are undoubtedly formed in this manner, and not by

the mere retirement of the tissues on either side, leaving an intervening channel. The closely-reticulated structure usually formed by the capillaries, has been commonly regarded as distinguishing them both from the arteries and the veins; and it is not unusual to speak of the arteries as delivering the blood into the 'capillary network,' and of the veins as receiving the fluid that has traversed this. Such expressions are not incorrect as implying the simple fact, that between the arteries and the veins is a network of minute vessels, through which the blood has to travel when proceeding from one to the other; but these vessels must not be regarded as belonging to a distinct class, being nothing else than the minutest subdivisions of the veins and arteries, which commonly inosculate freely with each other.

590. The degree of this inosculation, and the consequent form of the capillary network, are subject, however, to very great variations; and these may be generally shown to have a relation to the form of the ultimate elements of the tissues which are traversed by the capillaries. Thus we have seen in the capillaries of Muscle, that the major part run parallel to the course of the fibres, lying in the minute interspaces between them (Fig. 70); a few transverse branches serving to connect them with each other. A similar distribution prevails in the capillaries of the Nervous trunks; but those of the Nervous centres are arranged in the form of a minute network, so as completely to traverse every part of the structure (Fig. 99). Again, we observe that the capillaries of Glands form a minute network around the secreting follicles (Fig. 100); and a similar arrangement prevails in the capillaries of

Fig. 99.* *Fig.* 100.†





the air-cells of the lungs, which are set so closely together, that it would seem as if the purpose were to cover the surface with blood as completely as possible, consistently with its being retained within vessels, and not spread-out into a continuous film (Fig. 113). A

* Capillary Network of Nervous Centres.
† Capillary Network around the follicles of Parotid Gland.

network of very much the same character is found in the villi of the mucous membrane (Fig. 13), on the ordinary surface of simple mucous membrane (Fig. 101), and on that of the choroid coat of the eye (Fig. 102). Where the surface of the mucous membrane

Fig. 101.*

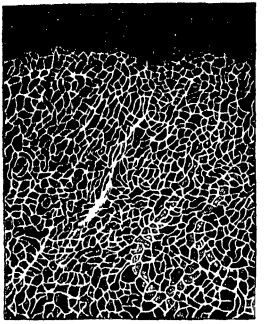
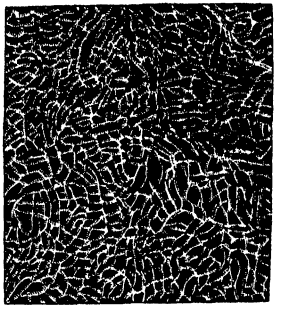


Fig. 102.†



is depressed into follicles, the arrangement of the capillaries has an evident reference to these (Fig. 103); whilst, on the other hand, where the surface of the skin is raised up into sensory papillæ, the capillary network sends looped prolongations into them, which are found accompanying their nerves (Figs. 104 and 105).

Fig. 103 ‡

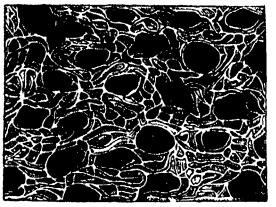


Fig. 104.§

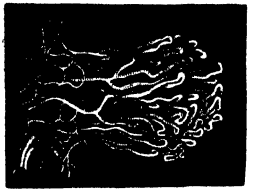


591. It cannot be supposed that the arrangement of the vessels has any further influence upon the function of the part they

* Capillary Network in simple Mucous Membrane of palpebral conjunctiva.
† Capillary Network in Choroid coat of the eye.
‡ Distribution of Capillaries around follicles of Mucous Membrane.
§ Distribution of Capillaries at the surface of the Skin of the finger.

traverse, than that which it derives from the regulation of the supply of blood afforded to each individual portion of the structure. The form of the capillary network is evidently determined by that of the elements of the tissues permeated by it; *these* are the real operative instruments in every part; and the distribution of the blood-vessels is so arranged, as to afford them precisely the amount of nourishment they respectively require. Thus we have seen that there are many living parts in the human body, possessing most important functions, which are not in any direct relation with blood-vessels, and which yet derive their whole nutriment and the materials of their functional operations from the blood. This is the case, for example, with the whole of the epithelial and epidermic cells; and also with the articular cartilages, and the substance of the teeth. Even in bone, the islets between the Haversian canals, which are completely unpenetrated by vessels, are of considerable size. Such islets must everywhere exist between the meshes of the capillary network; so that the question of the vascularity or non-vascularity of a tissue is one of *degree* only;—the ultimate fibre of muscle or nerve, and the cells and fibres of other tissues, being as completely non-vascular as the entire substance of a tooth or of an articular cartilage; the latter being nourished, like the former, by imbibition from the surrounding vessels.

Fig. 105.*



592. The term 'Capillary' may be employed in an extended or a restricted sense; in the former it includes *all* the minute vessels which pass between the arteries and the veins; in the latter it is applied only to those which admit no more than a single file of blood-disks at once, and excludes those which admit two, three, or even four rows, even although they establish a direct communication from one side of the network to the other. The former application of the term is the most convenient, although, perhaps not the most strictly accurate; and it will be therefore here employed in its extended sense. And this is rendered more correct by the fact, that the size of the individual capillaries is by no means permanent; an enlargement often taking-place in one, and a contraction in another, at the same time: so that vessels which were previously true capillaries, no longer remain such; and passages which were previously of far greater calibre, are reduced to the average diameter.

593. The opinion was long entertained, that there are vessels adapted to the supply of the white or colourless tissues; carrying

* Capillary network of Fungiform Papilla of the Tongue.

from the arteries only the fluid portion of the blood, or *liquor sanguinis*, and leaving the rest behind. No other such vessels have been really observed, however, than capillaries in a state of unusual contraction, as just now mentioned; and it may be safely affirmed that the supposition of their existence is not required. For any one who observes the smallest capillary vessels under the microscope, may perceive that the current of blood which passes through them is almost free from colour,—as the red corpuscles themselves appear to be, when spread-out in a single layer. Tissues which are rather scantily permeated by such vessels, therefore, may still be white; and it is only where the network is very close, and the quantity of blood which passes through it is consequently great, that a perceptible colour will be communicated by the red corpuscles. And we have seen that the idea that Nutrition can only be carried on by direct communication with vessels, is entirely unfounded; the tissues into which no blood-vessels can be traced, being adapted to nourish themselves, like cellular Plants, by the imbibition of fluid at their surfaces, on which vessels are (for the most part) copiously distributed.

594. That the blood can only minister to the operations of Nutrition, Secretion, &c. whilst it is circulating through the Capillaries, is evident from several considerations. The thickness of the walls of the larger vessels interposes an effectual barrier to its transudation; and so completely is the blood cut-off even from penetrating these, that they do not derive their own nourishment from the blood which flows through their tubes, but from a capillary network in their own substance, which is supplied by vessels from collateral branches,—these being termed the *vasa vasorum*. Moreover it is by the inosculation of the capillaries alone, that the minute network is formed, which serves to bring the blood into proximity with the minute parts of the tissues to be nourished; thus let it be supposed that the minute arteries of Muscle were to terminate in veins, without undergoing further subdivision, the *islets* left between their anastomosing branches would be far too large, and the nutritive materials would consequently not be supplied with sufficient readiness, even supposing that it could freely permeate the walls of these vessels.—The capillaries, then, must not be regarded as altogether distinct in their endowments from the vessels with which they are connected on either side; but merely as intended, by their minute subdivision and inosculation, to bring the blood into sufficiently close relation with the tissues they are to nourish, and to allow a greater degree of transudation of its elements by the comparative thinness of their walls. By a comparison in the rate of the blood's movement in the Capillaries with that of its movement in the Arteries, it is estimated by Volkman that the sectional area of any capillary network must be nearly four hundred times that of the arterial trunks which supply it.

595. When the flow of blood through the Capillaries of a transparent part, such as the web of a Frog's foot, is observed with the microscope, it appears at first to take-place with great evenness and regularity. The influence of the contractions of the heart may be seen to extend itself into the smaller arteries; the blood moving onwards in them with a somewhat jerking motion. But this influence altogether disappears in the capillary network; the flow of blood through this being even and continuous, except when the action of the heart is becoming weak and irregular, or when its influenee is impeded by obstruction in the vessels leading to the part,—the blood being then impelled by a succession of jerks, with intervals of complete repose. On watching the movement for some time, however, various changes may be observed, which cannot be attributed to the heart's influence, and which show that a certain regulating or distributive power exists in the walls of the capillaries, or in the tissues which they traverse. Not only do we occasionally perceive some of the tubes enlarging, so as to admit several files of blood-disks instead of one, whilst others that previously received several now only admit one; but we also see vessels coming into view which were not previously noticed, whilst other vessels seem to become obliterated. This apparently new formation and obliteration of vessels, however, does not really take-place; for a more close examination shows, that the former of these appearances is due to the entrance of red corpuscles into passages which existed before, but which were in such a state of contraction as enabled them only to admit the fluid portion of the blood: whilst, by a converse change in certain capillaries, from the dilated to the contracted state, the appearance of obliteration is produced, the red corpuscles being excluded, and the transparent fluid of the blood being alone transmitted by them.

596. But these are by no means all the irregularities, which may be detected by a close scrutiny of the Capillary circulation. The velocity of the current is liable to great and sudden variations, which cannot be accounted-for by any change in the heart's action, or in the supply of blood afforded by the arteries; and this change may manifest itself, either in the whole capillary network of a part, or in a portion of it: the circulation taking-place with diminished rapidity in one part, and with increased energy in another, though both are supplied by the same trunk. These variations are sometimes manifested by the complete change in the direction of the movement, in certain of the transverse or communicating branches; this movement taking-place, of course, from the stronger towards the weaker current. Not unfrequently an entire stagnation, of longer or shorter duration, precedes the reversal of the direction. Irregularities of this kind are most frequent, when the heart's action is enfeebled or partially interrupted; and it would thus appear that the local influences by which they are produced, are

overcome by the propelling power of the central organ, when this is acting with its full vigour. When the whole current has nearly stagnated, and a fresh impulse from the heart renews it, the movement is seldom uniform through the entire plexus supplied by one trunk; but is much greater in some of the tubes than in others,—the variation being in no degree connected with their size, and being very different in its amount at short intervals.

597. All these circumstances indicate that the movement of blood through the Capillaries is very much *influenced* by local forces; although these forces are not sufficiently powerful, in the higher animals, to *maintain* it alone. And from other facts it appears that the conditions necessary for the energetic flow of blood through these vessels, are nothing else than the active performance of those nutritive and other operations to which they are subservient. The examination of a single one of these processes, will afford us the requisite proof. The blood when circulating through the *systemic* capillaries, yields a portion of its oxygen to the tissues it permeates, and receives from them carbonic acid. On the other hand, when passing through the *pulmonary* capillaries, it gives-up its carbonic acid to the atmosphere, and imbibes a fresh supply of oxygen. Now if either of these changes be prevented from taking-place, a retardation and even a complete stagnation of the blood will occur,—the flow through the capillaries being now resisted, instead of accelerated, by the relation which the blood bears to the tissues. Thus it has been shown, that if an animal be partially deprived of oxygen, so that the arterial blood is not duly aerated (rather resembling the ordinary venous blood), and cannot exert its proper action on the tissues, the pressure upon the walls of the systemic arteries is *increased*, although the supply of blood propelled by the heart, and the propulsive power of the heart itself, are *diminished;* and this plainly indicates a retardation in the systemic capillaries, producing an undue accumulation in the arteries.—On the other hand, the suspension of the supply of oxygen to the lungs, either by an obstruction in the air-passages, or by the substitution of some other gas, brings the pulmonary circulation to a stand in a very short time, the blood not being able to undergo its usual changes in the capillaries of those organs; and by this stagnation, the whole movement of blood is speedily checked. The readmission of oxygen, if the suspension of the circulation have not been too long continued, occasions the renewal of the movement in the capillaries, and thence in the whole circle of vessels; and this even after the heart has ceased to propel blood towards the lungs.

598. The principles already noticed (§ 547) as put-forth by Prof. Draper, seem fully adequate to explain these phenomena. The arterial blood,—containing oxygen with which it is ready to part, and being prepared to receive in exchange the carbonic acid which the tissues set-free,—must obviously have a greater affinity for the

tissues than venous blood, in which both these changes have been already effected. Consequently, upon mere physical principles, the arterial blood which enters the systemic capillaries on one side, must drive before it, and expel on the other side of the network, the blood which has become venous whilst traversing it. But if the blood which enters the capillaries have no such affinity, no such motor power can be developed. On the other hand, in the capillaries of the lungs, the opposite affinities prevail. The venous blood and the air in the pulmonary cells have a mutual attraction, which is satisfied by the exchange of oxygen and carbonic acid that takes-place through the walls of the capillaries; and when the blood has become arterialized, it no longer has any attraction for the air. Upon the very same principle, therefore, the venous blood will drive the arterial before it in the pulmonary capillaries, whilst respiration is properly going-on: but if the supply of oxygen be interrupted, so that the blood is no longer aerated, no change in the affinities takes-place whilst it traverses the capillary network; the blood, continuing venous, still retains its need of a change and its attraction for the walls of the capillaries; and its egress into the pulmonary veins is thus resisted, rather than aided, by the force generated in the lungs.

599. The change in the condition of the blood in regard to the relative proportions of its oxygen and carbonic acid, is the only one to which the Pulmonary circulation is subservient; but in the Systemic circulation the changes are of a much more complex nature, every distinct organ attracting to itself the peculiar substances which it requires as the materials of its own nutrition, and the nature of the affinities thus generated being consequently different in each case. But the same law holds-good in all instances. Thus the blood conveyed to the liver by the portal vein, contains the materials at the expense of which the bile-secreting cells are developed; consequently the tissue of the liver, which is principally made-up of these cells, possesses a certain degree of affinity or attraction for blood containing these materials; and this is diminished, so soon as they have been drawn from it into the cells around. Consequently, the blood of the portal vein will drive before it, into the hepatic vein, the blood which has traversed the capillaries of the portal system, and which has given-up, in doing so, the elements of bile to the solid tissues of the liver.—The same principle holds good in every other case.

600. We are now prepared, therefore, to understand the general principle, that the rapidity of the circulation of a part will depend in great measure upon the activity of the functional changes taking-place in it,—the heart's action, and the state of the *general* circulation, remaining the same. When, by the heightened vitality or the unusual exercise of a part, the changes which the blood naturally undergoes in it are increased in amount, the affinities which

draw the arterial blood into the capillaries are stronger, and are more speedily satisfied, and the venous blood is therefore driven-out with increased energy. Thus a larger quantity of blood will pass through the capillaries of the part in a given time, without any enlargement of their calibre, and even though it be somewhat diminished; but the size of the arteries by which it is supplied soon undergoes an increase, which adapts it to supply the increased demand. Any circumstance, then, which increases the functional energy of a part, or stimulates it to increased nutrition, will occasion an increase in the supply of blood, altogether irrespectively of any change in the heart's action. This principle has long been known, and has been expressed in the concise adage, "Ubi stimulus, ibi fluxus;" which those Physiologists who maintain that the Circulation is maintained and governed by the heart alone, cast into unmerited neglect.

601. An undue acceleration of the local circulation, arising from an excess of functional activity in the part, and unaccompanied by any other change, constitutes the state known as *active congestion*, or *determination of blood*. This may be artificially produced by the application of gentle stimulants; and it is usually the first change that occurs, when their action proves sufficiently violent to produce Inflammation. From that state, however, it is distinguished by this important character,—that there is merely an *exaltation* of the *natural* function, but *no change*. Moreover, we shall presently see that, in Inflammation, there is a stagnation of blood, not an acceleration. We frequently meet with cases in which this active congestion becomes very manifest; especially in persons of active minds, who exert their mental powers too violently, and who thereby induce an habitually-increased flow of blood towards the head, manifested in the increased pulsation of the carotids, the suffusion of the face and eyes, and the heat of the surface. The balance of the circulation being thus disturbed, there is almost invariably a diminished energy of the movement of blood in other organs, especially the extremities; as is indicated by their habitual coldness and lividity. In the treatment of such a state (which is often the precursor of serious disease), it should be our object to restore the circulation in the extremities, by friction, exercise, &c.; and to abate the flow of blood towards the head, by restraining the functional activity of the brain, by the application of cold to the surface, by keeping the head high during sleep, and other means of similar tendency.

602. There is another condition of the capillary circulation, also known under the name of *Congestion*, which is precisely the opposite of the preceding. In this state, there is deficient functional energy in the part, and the circulation through it is consequently retarded,—as in the lungs, when there is a partial obstruction to the aeration of the blood. The same cause produces a deficient

tonicity of the Arteries, and allows their walls to be unduly distended by the *vis a tergo* of the blood; and consequently there is a great accumulation of blood in the part, with a retarded movement. This condition, like the preceding, predisposes to Inflammation, although in a different mode, as will be explained hereafter (§ 631). It is relieved by causes which promote the action of the part; thus congestion of the lungs, occasioned by the effusion of fluid into the air-cells, which creates an obstacle to the aeration of the blood, disappears when that effusion is absorbed. And congestion of the liver, the result of deficient secreting power in the organ, is relieved by mercurial and other medicines, which promote the flow of bile by stimulating the action of the hepatic cells.

603. The Capillaries, like the Arteries, possess a power of contraction and dilatation, which seems to be very much under the influence of the Nervous System, and particularly of that part of it which conveys the influence of the Emotions. We have a *visible* example of this influence in the act of *blushing*, which consists in a sudden enlargement of the capillaries and small vessels of the surface; whilst the converse state of *pallor*, which often alternates with it under the influence of strong emotion, is evidently due to an unusual contraction of the same vessels. But the effects of this influence are no less sensible in other cases; and particularly in the regulation of the quantity of certain secretions, in accordance with the mental state or with the condition of the system generally. To the mode in which this regulation is effected, the act of blushing seems to afford us the key; for it indicates that the supply of blood afforded to the glands, may be entirely governed by the influence of the nervous system upon the calibre of the arteries. Thus the nursing mother, at the sight, or even at the thought, of her child, when the usual time for suckling approaches, feels a rush of blood to the breast, exactly resembling that which takes-place to the cheeks in blushing, and popularly termed 'the draught;' this rush occasions an almost immediate increase in the secretion. In like manner we may explain the influence of the mental state upon the *amount* of the secretions of the lachrymal, the salivary, and many other glands; its influence upon their *quality* must probably be effected through changes in the condition of the blood itself.

604. The supply of Nervous agency from the Cerebro-spinal system, has been clearly proved to exert no direct influence in maintaining the capillary circulation; since the latter continues as usual, after all the nerves of a part have been divided. This is obviously due to the fact, that the operations of nutrition, secretion, &c., are essentially independent of this agency. But as *they* are in some degree *influenced* by it, so will the capillary circulation be affected, through its connection with them. In this manner we are to explain the effect of violent impressions upon the nervous

centres, in bringing to a stand, not merely the action of the Heart (§ 581), but the Capillary circulation all over the body. The general vitality of the system appears to be at once destroyed; so that the capillary circulation, which may usually be seen to continue in the web of a frog's foot for some time after the interruption of the heart's action, is immediately suspended by crushing the brain with a hammer.

6. *Of the Movement of Blood in the Veins.*

605. The Venous system is formed by the reunion of the small trunks which originate in the capillary network; and it carries back to the heart the blood which has been transmitted through this. Such blood is *dark* or carbonated in the *systemic* veins; whilst it is *bright* or oxygenated in the *pulmonary* veins.—The structure of the veins is essentially the same with that of the arteries; but the fibrous tissue of their middle coat less decidedly exhibits the characters, either of the yellow elastic tissue, or of non-striated muscle. Still it possesses no inconsiderable amount of Elasticity; and a certain degree of Muscular contractility also. The whole capacity of the Venous system is at least *twice*, and perhaps more nearly *three times*, that of the Arterial; and the rate of motion of the blood in it must be proportionably slower.

606. The movement of the Blood through the Veins is, without doubt, chiefly effected by the *vis a tergo*, or propulsive force, which results from the contractile power of the heart and arteries, aided by the power generated in the capillary vessels. The intermittent flow which is caused by the interrupted action of the former, is usually so far equalized during the passage of the blood through the capillary network, that no pulsation can be shown to exist in the veins; but instances occasionally present themselves, in which a venous pulse may be clearly perceived.—The Venous Circulation is affected, however, by certain other causes, which exert little influence on the movement of blood in the Arteries. One of these is the frequently-recurring action of Muscles, to which the Veins are peculiarly subject, on account of their position. In every instance in which Muscular movement takes-place, a portion of the Veins of the part will undergo compression; and as the blood is prevented by the valves in the veins from being driven-back into the small vessels, it is necessarily forced-on towards the heart. As each set of muscles is relaxed, the veins that were compressed by it fill out again, to be again compressed on the renewal of the force. Thus we see how the general Muscular movements of the body have an important influence in maintaining the Venous Circulation,—how continued exercise, involving the alternate contraction and relaxation of several groups of muscles, must send the blood more rapidly towards the heart, and thus increase the rapidity of its pulsations,

—and how the sudden and simultaneous action of a large number of muscles after repose (as when we rise-up from the sitting or lying, to the standing posture), may drive the blood to the heart with so violent an impetus, as to produce even fatal results, if, by any diseased condition of that organ, it should be rendered unable to dispose with sufficient rapidity of the quantity of blood thus transmitted to it.

607. The Respiratory movements exert a slight influence upon the flow of blood through the large veins near the heart; for as the chest is a closed cavity, in which a partial vacuum is produced by the act of Inspiration, whilst its contents are compressed by the act of Expiration, the former state will favour the movement of blood from the large veins on the exterior of the cavity towards the heart, whilst the latter condition will retard it. This produces the phenomenon termed the *respiratory pulse;* which may be seen in the veins of the neck and shoulders in thin persons, and especially in those who are suffering from pulmonary diseases. The influence of the Respiratory movements is made evident by introducing a tube into the Jugular vein, the lower end of which dips into water; for an alternate elevation and depression of the water into the tube is then witnessed, showing the suction-power of the Inspiratory movement, and the expellent force of the Expiratory act.—On the other hand the Expiratory movement, while it directly tends to cause accumulation in the veins, will assist the heart in propelling the blood in the Arteries; and by the combined action of these two causes there is produced, among other effects, a rising and sinking of the Brain, synchronously with expiration and inspiration, which are observed when a portion of the cranium is removed.

608. A pulsatory movement may be occasioned in the great veins near the heart, by another cause entirely distinct from the preceding;—namely, the regurgitation of blood from the ventricle into the auricle, and thence into the venæ cavæ, during the *ventricular* systole; and the pulsation thus occasioned is synchronous, therefore, with that in the arteries (proceeding *backwards*, however, from the heart), instead of corresponding with the respiratory movement. This regurgitation may take-place, not from any disease in the valves on the right side of the heart, but simply from over-distension of its cavities, resulting from any obstruction to the circulation of blood through the lungs; for when this occurs, the tricuspid valve does not completely close, and allows a portion of the blood to escape from the ventricle backwards into the auricle and venæ cavæ. This want of complete closure, constituting what has been termed the 'safety-valve function' of the tricuspid valve, has been particularly noticed in diving animals, in which the circulation through the lungs is liable to be temporarily suspended. The venous pulsation which is thus produced, may be noticed in almost every case of long-standing dyspnœa; especially when this is

accompanied (as it usually is) by hypertrophy and dilatation of the right ventricle of the heart.

609. The Venous circulation is much more liable than the Arterial, to be influenced by the force of Gravity; and this influence is particularly noticeable, when the Tonicity of the vessels is deficient. The following experiments performed by Dr. Williams, to elucidate the influence of deficient firmness in the walls of the vessels, and of gravitation, over the movement of fluids through tubes, throw great light on the causes of Venous Congestion.—A tube with two equal arms having been fitted to a syringe, a brass tube two feet long, having several right angles in its course, was adapted to one of them, whilst to the other was tied a portion of a rabbit's intestine four feet long, and of calibre double that of the brass tube, this being arranged in curves and coils, but without angles and crossings. When the two ends were raised to the same height, the small metal tube discharged from two to five times the quantity of water discharged in a given time by the larger but membranous tube; the difference being greatest, when the strokes of the piston were most forcible and sudden, by which the intestine was much dilated at its syringe-end, but conveyed very little more water. When the discharging ends were raised a few inches higher, the difference increased considerably, the amount of fluid discharged by the gut being much diminished; and when the ends were raised to the height of eight or ten inches, the gut ceased to discharge, each stroke only moving the column of water in it, and this subsiding again, without rising high enough to overflow. When the force of the stroke was increased, the part of the intestine nearest the syringe burst.

610. From these experiments it is easy to understand, how any deficiency of tone in the Venous system will tend to prevent the ascent of the blood from the depending parts of the body, and will consequently occasion an increased pressure on the walls of the vessels, and an augmentation in the quantity of blood they contain. All these conditions are peculiarly favourable to the escape of the watery part of the blood from the small vessels; and this may either infiltrate into the areolar tissue, or it may be poured into some neighbouring serous cavity, producing dropsy. Thus it happens, that such effusions may often be traced to that state of deficient vigour of the system, which peculiarly manifests itself in want of tone of the blood-vessels; and that it is relieved by remedies which tend to restore this. In many young females of leuco-phlegmatic temperament, for example, there is a tendency to swelling of the feet, by œdematous effusion into the areolar tissue, in consequence of the depending position of the limbs; the œdema disappears during the night, but returns during the day, and is at its maximum in the evening. And the congestion which frequently manifests itself in the posterior parts of the body, towards the close

of exhausting diseases, in which the patient has lain much upon his back, is attributable to a similar cause; of such congestion, effusions into the various serous cavities are frequent results; and such effusions, taking-place during the last hours of life, are often erroneously regarded as the cause of death. To the same cause we are to attribute the varicose state of the veins of the leg, which is so common amongst persons of relaxed fibre, and especially in those whose habits require them to be much in the erect posture; and this distension occasionally proceeds to complete rupture, the causes of which are fully elucidated by the experiments just cited.

611. It has been thought that the circulation within the Cranium is subject to different conditions from that of other parts of the body. For it has been argued that, as the cranium is a closed cavity,—a certain part of which is occupied by the cerebral substance and its membranes, and the remainder filled-up with blood,—the amount of blood in the vessels of the brain must be always the same, so that any disturbance of its circulation must be due to a difference in the relative quantity of blood in the arteries and the veins. This idea appeared to derive support from the results of experiments, which showed that the blood is retained in the vessels within the cranium of animals bled to death, unless an opening be made in the skull, so as to allow the air to exert the same pressure upon these vessels as upon those of other parts. But such experiments do not at all sanction the assertion that the quantity of blood within the cranium is constant; on the contrary, we have reason to believe that it undergoes as much change as in other parts. For although the cerebral substance be incompressible, yet its bulk is subject to constant variation, according to the quantity of fluid it contains; and the presence of the 'cerebro-spinal fluid' in the sub-arachnoid cavity of the brain and spinal cord, appears to be peculiarly destined to favour this continual change,—the proportions of it contained in the spinal and the cerebral cavities respectively, being governed by the bulk of the other contents of the cranium. Thus if the vessels of the cerebrum be in their ordinary state of fulness, a certain amount of fluid is present in the sub-arachnoid cavity of the brain; this will be pressed-out into the spinal portion of the cavity, if the cerebral vessels be unusually distended with blood; whilst it will be increased from the latter source, so as to fill-up the vacant space within the cranium, if the cerebral vessels be unusually empty.

CHAPTER VII.

OF NUTRITION.

1. *Selecting Power of the Individual Parts.*

612. THE Blood which is carried into the different parts of the system, by the Circulating apparatus, is the source from which all the organs and tissues of the body derive the materials of their growth and development; and, as we have seen, it is distributed by the Capillaries of the several tissues, with a degree of minuteness which varies according to the activity of the nutrient operations in the respective parts. Thus, in Nerve and Muscle, Mucous Membrane and Skin, a constant decay of the old and a development of new tissue are taking-place, when these organs are in a state of functional activity, and a copious supply of blood is carried through every part of their substance: whilst in Cartilage and Bone, Tendon and Ligament, the amount of interchange is very small, and is affected by a much less minute reticulation of capillary blood-vessels.

613. The *materials* of the nutritive process being prepared in the blood, the process of nutrition is the act of each individual part; which grows and developes itself, in virtue of its own inherent powers, so long as the requisite conditions are supplied. The mode in which this takes-place, in each individual tissue, has been already explained in the former part of this Treatise. We have seen that, in the great majority of cases, the act of Nutrition is, in fact, a process of cell-growth; and that it takes-place under the same conditions as the production of the simple isolated cell, which constitutes the whole of the humblest forms of Cryptogamic Vegetation,—namely, that it grows from a germ, which draws to itself the materials of its nutrition, and gives to some of them a new arrangement, whereby they form the cell-wall, whilst others are introduced into the cell-cavity,—and that when it has passed through its regular series of changes, it dies, and sets-free its contents. We have seen that, in some cases, the germs appear to be formed by the aggregation of molecules contained in the plastic fluid; whilst in others they are prepared by previously-existing cells of the same kind. Frequently it would seem as if the original or parent-cell is able to continue the production of secondary cells to an unlimited extent, even though it may have itself undergone a considerable change of form. Thus the ultimate follicles of

Glands have at first the character of closed cells, which subsequently open at the part nearest to the duct, and establish a connection with it; and having thus changed their condition, they go on developing new generations of secreting cells in their interior, from their own nuclei or germinal centres, to an unlimited extent.

614. The selecting power which is possessed by the germs of each kind of tissue, and which enables them to draw from the blood the materials which they severally require for their development, manifests itself also in the mode in which substances that are abnormally present in the blood, affect the condition and development of the solid tissues. Thus we find that the presence of a certain quantity of Arsenic in the blood, will produce a state of irritation in all the mucous membranes of the body. The continued introduction of Lead into the circulating system, occasions a modification in the nutrition of the extensor muscles of the forearm, producing the form of partial paralysis commonly termed 'wrist-drop;' and the existence of this modification is shown by the presence of lead in the palsied muscles. Here we have to remark the *symmetrical* nature of the affection, consequent upon the occurrence of the same disorder in the corresponding parts of the two sides of the body; for these muscles appear to have the same kind of tendency to attract lead from the circulating current in a degree that is equal on the two sides, as they have to draw from the blood the materials of their regular growth so as to develope themselves in an exactly-similar manner. In like manner, the cutaneous eruptions which are occasionally produced by the internal exhibition of iodide of potassium, are found to be almost precisely symmetrical; the presence of the medicine in the blood being the occasion of a disordered nutrition of certain parts of the skin, and the selecting power of particular spots being evinced by the exact correspondence of the parts affected on the two sides.

615. The same appears to be the case with regard to substances, whose presence in the blood is rather the result of a disordered condition of the digestive and assimilating processes, than of their direct introduction from without. Thus in Lepra and Psoriasis,—chronic diseases of the Skin, which seem to have their origin in a depraved state of the blood, rather than in the solid tissues affected,—we find a remarkable tendency to the repetition of the patches on the two sides of the body, or on the corresponding parts of the limbs; and this we can attribute to nothing else than the peculiar attraction, existing between the solid tissues of those parts and the morbid matter circulating through them. So in those chronic forms of Gout and Rheumatism which modify the nutrition of the joints, producing a deposit of 'chalk-stones,' or permanent distortion and stiffening, we almost invariably find the corresponding joints of the two sides affected. The chief exceptions to the general principle, that the presence of morbid or extraneous matters in the blood

affects corresponding parts alike, are found to exist where there is much febrile disturbance, or where local causes produce a peculiar tendency to disorder of a single part. The nearer the character of the morbid process is to that of the ordinary nutritive operations, the more nearly does it approach these, in the *symmetry* with which it developes itself.*

2. *Varying Activity of the Nutritive Processes.*

616. The nutritive operations go-on with very great variations in their relative activity, under different circumstances. As a general rule, it may be stated that the greater the demand for the functional activity of the organ or tissue, the more energetic is its nutrition; and *vice versâ*. Now this is readily understood, when it is considered that the active state of many structures essentially consists in an act of nutrition; thus the energy of the secreting processes is really dependent, as we have seen, upon the growth of the secreting cells which make-up the essential part of the gland; and the energy of the absorbing and assimilating processes is dependent upon the development of the cells which select and elaborate the nutrient matter. This growth is regulated mainly by the supply of blood; being increased by the afflux of blood towards the part, in consequence of the influence of the nerves upon the vessels, or through any other change in the current of the circulation. Thus the secretions are augmented in amount by emotions of the mind, that act (probably through the sympathetic nerve) in regulating the calibre of the arteries supplying their respective glands; or the interruption of the function of one gland shall occasion an increased nutrition, and consequently an augmented secretion in its fellow,—as when one of the kidneys is hypertrophied through a disease in the other, that renders it incapable of performing its office. Still it would appear that there may be variations in the activity of these organs, resulting from causes inherent in themselves (of the nature of which we know little or nothing); and that here as elsewhere, active nutritive operations will promote the circulation of blood through the parts, whilst a languid state of their function will retard it.

617. In certain other tissues, however, the functional activity would seem rather to involve a *waste* or *decay* of structures previously developed; this is the case especially in Nerve and Muscle, which are found to undergo disintegration in exact proportion to the degree in which they are exercised; whilst the degree in which this waste is repaired, depends upon the supply of nutritive material, the quiescent state of the part, and other circumstances. But

* See Dr. W. Budd's valuable Paper on the "Symmetry of Disease," in Vol. xxv. of the Medico-Chirurgical Transactions.

even here we find that functional activity occasions increased nutrition, in the same manner as burning a lamp with a high flame increases the amount of fluid drawn-up by the wick. For neither the nerves nor the muscles can act with energy, without a large supply of arterial blood; and this is drawn to them by the agencies already mentioned (§ 600) as increasing the energy of the local circulation. The determination of blood to the parts, thus established, favours their increased nutrition; and thus we find that, under favourable circumstances, any set of muscles which is habitually exercised, undergoes a great increase of development; whilst, in like manner, the Nervous centres, if too great a demand be made upon their activity, are liable to become hypertrophied (especially in young persons), and may thus become subject to disorders, which temporarily or permanently destroy their powers. In these cases, then, the functional activity determines the increased supply of blood, and occasions the augmented growth; and increased nutrition will rarely take-place in these tissues without an especial stimulus of this kind. Thus we find that, when a larger supply of nutritive matter is introduced into the circulation, than is required to repair the waste of these tissues, they do not undergo an increased development in consequence; but an augmented nutrition is produced, either in the adipose tissue, or in the glandular structures by which the superfluous matter is eliminated from the system.

618. Augmented nutrition or *Hypertrophy*, then, may result, in certain organs, from an excessive supply of their nutrient materials: as in the case of the kidney just mentioned; or as in the enlargement which we not unfrequently meet-with in the livers of those who have resided long in warm climates, and who have not sufficiently restricted their supply of non-azotized food to the small amount required for respiration at an elevated temperature, thereby sending an over-supply of that particular class of bodies to be separated from the blood by the liver. In other cases, again, the increase of functional activity may be the immediate cause of the increased nutrition; and this we see, not only in the nervous centres and voluntary muscles which are put in action by the will, but in parts over which the mind has no control. Thus the heart becomes hypertrophied when an obstruction exists in the pulmonary or systemic circulation, to overcome which, increased energy of contraction is required; and in the same manner, the muscular coats of the urinary and gall-bladder acquire an extraordinary increase of thickness, when long-continued obstruction, by calculi or stricture in the canals issuing from them, impedes the free exit of their contents. Sometimes, however, a local hypertrophy takes place, which cannot be accounted-for in either of these modes: as when a single finger is enlarged out of all proportion to the rest, or the whole of one hand increases to a much greater size than the other, by the existence (as it would seem) in the individual part, of that tendency to unusual

development, which, when it affects the whole body uniformly, produces a gigantic stature.

619. Now a precisely-reversed series of conditions diminishes the activity of the nutrient processes, and induces a state of *Atrophy*. If there be a deficiency in the general amount of nutriment introduced into the system by absorption, a *general* atrophy results; and the waste being more rapid than the supply, there is a diminution in the volume of all the tissues excepting the nervous, which seems to have its nutrition kept-up even to the last, at the expense of all the rest. Such a condition results not merely from the want of food, but also from the want of power to assimilate it; and thus emaciation may take-place to an excessive degree, when food of the most nutritive character is copiously supplied, and when the appetite for it is vehement; in consequence of disorder in the mesenteric glands, or in some other part of the apparatus particularly concerned in the elaboration of organizable material. A *partial* atrophy may result, in like manner, from a deficiency of the materials required for the formation of an individual tissue or organ; thus the adipose tissue throughout the body may be atrophied, in consequence of an absence of those materials in the food which are capable of being converted into fatty matter. Or a particular organ may be atrophied, by a diminution of the circulating current that should flow to it, either in consequence of obstruction in the trunk, or by the partial diversion of the stream of blood in another direction; thus the liver, which is much more developed in the fœtus, relatively to the rest of the body, than it is in the adult, undergoes a partial atrophy immediately after birth, in consequence of the change in the whole course of the circulation, which takes-place as soon as the lungs are expanded.

620. But partial atrophy may also take-place from causes inherent in a particular organ. Thus we occasionally meet with limbs which are 'blighted,' never attaining their due size relatively to the remainder of the body, yet not exhibiting any defect of organization. Here there would seem to be, from some unknown cause, a deficient power of growth; analogous to that which, when acting on the body in general, confines it within dwarfish dimensions.—One of the most frequent causes of partial atrophy, however, is want of functional activity in the organ; and this is particularly the case in regard to the Muscular and Nervous systems. Thus, as already remarked (§ 348), any set of Muscles that is long disused, becomes partially atrophied; which is probably due to the feebleness and languor of the circulation, consequent upon the absence of the demand for arterial blood. As soon as the parts are called into use again, their nutrition improves. So, also, in regard to the Nerves: for the nutrition of both the fibrous and vesicular structures appears to be entirely dependent upon the activity of their function; and as the former are inert without the latter, we may say that the due

nutrition of the nervous system entirely depends upon the functional activity of the vesicular matter. Of this we have a well-marked illustration in the fact, that when the cornea has been rendered so opaque by disease or accident, as to prevent the penetration of any light to the interior of the eye, the retina and the optic nerve lose after a time their characteristic structure; so that scarcely a trace of the peculiar globules of the former, or of the nerve-tubes of the latter, can be found in them.

621. In the healthy condition of the organism, however, the nutrition of every part of the body goes-on in a degree sufficient to keep it constantly ready for the performance of its appropriate function; a regular supply of the requisite materials being furnished in the aliment, and being prepared by the assimilating processes; and the products of the waste or decay of the tissues, together with such alimentary materials as may be superfluous, being carried-off by the excreting operations. When the nutrition and the waste are equal, the weight of the body remains the same; and this is commonly the case in adult age. But during the earlier periods of life, the powers of growth are greater; the demand for food is very large in proportion to the bulk of the body; and though the waste is rapid, and the excreting processes very active (as evinced by the large amount of urea and of carbonic acid set free), the growth predominates over the decay, and the development of the whole structure proceeds at a gradually-increasing rate, until the full stature and bulk are attained. The energy of the nutritive process is particularly manifested, in the rapidity and completeness with which severe injuries occasioned by disease or accident are repaired. In advanced life, on the contrary, although the waste is comparatively small, the renewing processes are enfeebled in a still greater degree; and there is a gradual diminution in the stature and bulk of the body, and in its physical powers. All the functions are performed with decreased energy; and the comparative inertness of the nutritive processes is seen in the difficulty with which the effects of severe injuries are repaired, as shown in the length of time requisite for the purpose, and frequently in the imperfection of the result.

622. During the successive periods of life, there are many remarkable changes in the relative nutrition of different organs, which we can attribute to nothing else than to inherent differences in their own powers of development. Thus, during the early stages of fœtal existence, the greatest energy of growth is seen in certain parts which are to answer but a temporary purpose, and which are afterwards completely atrophied. This is the case, for example, with the Corpora Wolffiana, which seem to answer the purpose of temporary kidneys, and in connection with which the permanent kidneys and the genital organs are developed; and of these bodies, though of large size in the early embryo, and evidently of great

importance, no trace whatever is afterwards to be discovered. So in regard to the Supra-Renal capsules, the Thymus and Thyroid glands, and other organs, we find their proportional size the greatest, and their function evidently the most active, during fœtal existence and in early infancy; after which their bulk diminishes in proportion to the rest of the body, and their functional activity seems almost at an end.

623. Even in the relative development of the organs which form essential parts of the permanent structure, we find considerable variations at different periods of life. Thus the evolution of the generative system does not usually take-place, until the rest of the body is approaching its maturity; but cases sometimes occur, in which this apparatus attains its full development, both in the male and in the female, at a very early period of childhood, and seems capable of performing its functions. In the Human species, these organs when once evolved remain always in a state of preparation for the performance of their function, unless they are atrophied through complete disuse, or have lost their vigour by age, or through excessive demands upon their activity: but in most of the lower animals, the development of these organs is periodical through the whole of life, taking-place at a certain season of the year, and being greatly influenced, it would appear, by the external temperature and by the supply of food. Thus in the Sparrow, the testes are no larger than mustard-seeds during the greater part of the year; but in the spring, they acquire the size of large peas, and it is then only that they possess any procreative power.

624. We are not always to judge of the degree of development of organs, however, by their *size* alone; for the completeness of their structure, and their aptitude for the performance of their functions, must also be taken into the account. Thus in the new-born infant, the organs of Digestion and Assimilation, though of small size, are so completely formed as to be able at once to take-on the duty of receiving and preparing the nutritive materials, provided these are supplied in a form adapted to their powers; the Circulating apparatus is fully adequate to transmit the products of the action of those organs to the body in general, and to bring-back the results of its continual decay; and the Respiratory organs, together with other parts of the Excretory apparatus, are so completely evolved, as to be able to separate the effete matter, and to cast it out of the system, with an energy equivalent to that of the organs by which new matter is introduced and appropriated. On the other hand, the Brain, although of larger comparative *size* at birth than at any subsequent period of life, is but very imperfectly developed; for its structure is not yet so far completed as to prepare it for a state of high functional activity. In fact, it would seem as if the use of the organ, called-forth by the new circumstances in which the infant is placed as soon as it comes into the world, is essential to

its complete development; and the same may be said of the Muscular system.

625. During the whole period of infancy and childhood, the current of nutrition seems peculiarly directed towards the brain; for though its *size* does not continue to increase in proportion to that of the remainder of the body, its *structure* is evidently being rendered more perfect, and its functional activity is excited with remarkable facility. Hence it is peculiarly liable to be acted-on by various causes which may produce disease; and the operation of remedies which specially affect that organ, is far more powerful than at any other period of life. Thus, whilst a child will bear a fourth, or even a third, of the dose of a purgative adequate for an adult, it is strongly affected by an eighth or even a twelfth of the dose of a narcotic or a stimulant, that would be required to produce a corresponding effect in middle life. This peculiar impressibility of the nervous system, resulting from the activity of the nutrient processes which are taking-place in it, manifests itself also in other ways; thus children are peculiarly liable to have its powers depressed by any sudden shock, such as a blow, or an extensive burn or laceration; whilst, on the other hand, if the depression be not fatal, they recover from its effects much more speedily than an adult would do from a similar condition.

626. During the periods of youth and adolescence, the chief energy of development (except in regard to the generative system, already noticed) appears to be directed towards the Muscular apparatus, which then increases in vigour in a degree that surpasses its increase of size; and the circulating and respiratory organs, upon whose energetic action there is then a corresponding demand, are peculiarly liable to disturbance of function, inducing disease in themselves or in other parts. The maladies of this period are for the most part of a *sthenic* or *inflammatory* character; resulting, as we shall presently see, from the excessive activity of the assimilating processes, which are disposed to produce more plasma than the wants of the body require. Or if, on the other hand, there be an imperfect elaboration of the nutrient materials, as happens in the *tubercular* diathesis, its effects are peculiarly liable to manifest themselves at this period, when the demand for nutritive matter is greatly augmented by the activity of the muscular system.

627. In adult age, there should be such a balance of all the functions, arising from the due development and proper use of each organ, as may preserve the body in the state of health and vigour, without any marked change in the relative dimensions of its different parts, through a long series of years. The digestive, assimilating, and excreting organs, as they were the first to come to maturity, are commonly the first to fail in their activity; but this is very generally the result of over-exertion of their powers, the amount of food introduced into the stomach being rarely (among the

higher and middle classes of society at least) kept-down to the real wants of the system. The muscular apparatus usually experiences the effects of this diminished nutrition sooner than the nervous system; the vigour of the latter being often sustained in a remarkable degree (as is shown by the energy of the mental operations) through a protracted life, when it has not been over-tasked at an earlier period. The very slight impairment of the nutrition of the nervous system, during the general emaciation which results from a wasting disease, or during that more gradual decline of the bodily vigour which is consequent upon advancing age, is a phenomenon which strongly marks it out as the part of the body to the maintenance of whose integrity everything else is subservient; and this is still more strikingly shown in the phenomena of starvation, in which state, notwithstanding the disappearance of the whole of the fat, and the reduction of the weight of the body in general by about 40 per cent., the nervous system appears to lose little or none of its substance (§ 117).

3. *Of Death, or Cessation of Nutrition.*

628. The general cessation of the Nutritive operations in *Death*, usually depends, as formerly explained (§ 64), upon the cessation of the supply of Nutriment, in consequence of the stagnation of the Circulating current; and this stagnation may result from the *direct* operation of three causes; namely,—failure in the propulsive power of the Heart, or *Syncope*,—obstruction to the flow of blood through the pulmonary capillaries, consequent upon a deficient supply of air, or *Asphyxia* (§ 706),—and a disordered state of the blood itself (§ 534), which at the same time weakens the power of the heart, and prevents the performance of those changes in the systemic capillaries which afford a powerful auxiliary to the circulation; a mode of death, for which the term *Necræmia* has been proposed. Each of these conditions may be dependent upon a variety of remote causes, which cannot be here particularized. But it is evident that, when either one of them has been established, the nutritive processes must speedily cease, although they may continue for a short time at the expense of the blood in the capillaries of the part. The cooling of the body is another cause of their cessation; and this is one reason why *molecular* death (or the death of the individual organs and tissues) follows so much more closely on *somatic* death (or the cessation of the circulating and respiratory functions) in warm-blooded than in cold-blooded animals. In either case, however, the solid tissues may preserve for a time their independent vitality; and changes may take-place in them, which indicate the continuance of their nutritive actions to a certain extent, even when they have been entirely disconnected from the body.—There are undoubtedly cases, however, in which the loss of vital power is as

complete and immediate in the solids as in the fluids; the want of ability to avail themselves of nutriment being as decided in the former, as the deficiency of supply is in the latter. This is seen, for example, when death results from a sudden and violent shock, which destroys the vitality of the whole system alike (§ 604); molecular death being here consentaneous with somatic.

629. But as each component part of the Animal fabric has an individual *life* of its own, so must it have a *limited duration* of its own; the *period of termination* of its vital activity, or its *death*, being quite independent of that of the body at large, excepting in so far as the operations of the latter are requisite to afford it a constant supply of appropriate nutriment, and to maintain its temperature at the proper elevation. It is perfectly compatible, on the other hand, with the Life of the entire organism, that certain parts of it should be continually in course of decay and renewal; and, in fact, we find that the most important parts in the vital functions are performed by tissues whose individual duration is comparatively brief, but which are renewed as fast as they degenerate. We have a well-marked example of this in the case of the leaves of trees, which are the chief agents in the preparation of the nutritious fluid at whose expense the permanent tissues of the trunk and branches are generated; and although there is nothing in the Animal body at all comparable to the complete exuviation which commonly takes-place in the Plant at the close of the season of vegetative activity, yet there is a continual death and separation of parts that have performed their function, which in the end makes-up a much larger aggregate. Thus there is scarcely a less complete renewal of the epidermis in Man, in the course of twelve months, than there is in Serpents, Frogs, &c., which throw it off periodically; the only difference being, that in the one case the whole is exuviated and renewed at once, whilst in the other there is a continual interchange. In the exuviation of the antlers of the Deer and of the milk-teeth of all Mammalia, we have very marked examples of this limitation of the life of individual parts even in the highest Animals; and as a general proposition it may be stated that every part must degenerate, when it has gone through the whole series of changes in which its Life consists, and that it must then either die and decay, or must be so altered in its constitution as to be able to remain inactive without further change.

630. Hence we see that the duration of vital activity must be *cæteris paribus* in the inverse ratio of its energy; that is, the life of any part, or of the entire organism, must be shortened by any excess of functional activity; whilst it may be prolonged by such a degree of repose, as does not involve an impairment of its nutrition. We see this most remarkably exemplified in the case of cold-blooded animals; the duration of whose lives, after they have sustained some fatal injury (such as the removal of the heart or of the lungs),

or are placed in any other circumstances incompatible with its continuance, is in the inverse proportion to the elevation of the temperature to which they are exposed, and therefore to the degree of their vital activity (§ 128). Now although, in consequence of the comparative uniformity of the temperature of warm-blooded animals, such variation is comparatively little observable in the rate of life of that portion of their fabric which is concerned in their organic functions, it is clearly seen in those organs whose functional activity is more under the control of the individual, and is therefore less constant. Thus, in Man, we continually notice that the duration of the powers of the Brain and of the Generative system is the longest when these organs have been moderately exercised, and that it is much curtailed by the excessive use of either. The duration of their activity, however, is not increased by partial or entire disuse of the organs; for this induces a state of atrophy, on the principles already mentioned.—Now we have every reason to believe that what is true of individual parts and organs, is true also of the whole structure; and that the existence of the entire bodily fabric may thus come to an end without any special disease, in consequence of the limit originally set to its powers of self-renovation. It is but rarely, however, that this occurs; the various accidents of life, the neglect of ordinary precautions for the preservation of health, and hereditary tendencies to various kinds of morbid action, being too frequently the means of cutting-off the term of Human existence, long before its natural expiration.

4. *Disordered Conditions of the Nutritive Processes.*

631. Having thus passed in review the general conditions under which the ordinary Nutritive processes take-place, it may be well to add a few words in relation to two of their abnormal states; one or other of which is concerned in a very large proportion of the diseases that afflict the human race. In one of these, there is a tendency to the excessive production of fibrin in the blood; whilst in the other, there is a want of the proper nutritive power in the tissues, which is apparently due to an imperfect elaboration of the organizable plasma. The one of these conditions is termed *Inflammation;* whilst the other, which is less active but more insidious, is known as the *Tubercular Diathesis.*

632. The extraordinary tendency to the production of Fibrin in the blood, which has been already noticed (§ 531) as one of the most important characters of Inflammation, seems to be always conjoined with a depressed vitality of the tissues of some part of the body, which indisposes them to the performance of their regular nutritive operations; and this part may undergo a variety of changes, according to the degree in which it is affected. The depressed condition of its nutritive operations involves, on the

principles explained in the preceding chapter, a languor in the movement of blood through it, together with a distensible state of the capillaries, which causes them to contain a far greater amount of that fluid than under ordinary circumstances. On the other hand, there is a tendency to the production of an increased amount of plastic material in the blood, as if for the reparation of the part whose vitality is lowered. What is the immediate cause of this production is still doubtful; but we see the consequences of the deficiency of it in those *asthenic* or unhealthy Inflammations, which so frequently involve the destruction of a large amount of tissue; the degeneration of the part first affected soon extending itself to others, if there be no limit set-up by the reparative powers of the blood.—In ordinary or *sthenic* Inflammation, of which the increase of fibrin in the blood, and a diminution in the self-nutritive power on the part of the tissues, are the most characteristic phenomena, the simplest result is the effusion of blood-plasma, or 'organizable lymph,' into the substance of the part inflamed, or upon the nearest free surface; and thus is produced a condensation of the tissue, or a new growth upon the membrane. But when the depression of vitality is more complete, the tissue at that spot gradually dies and disintegrates; and whilst itself undergoing such changes, it gives origin to similar changes in the effused fibrin, which it converts from a *plastic* or organizable deposit, into an *aplastic* or unorganizable one, namely, *pus*, the cells of which degenerate without passing into any higher or more permanent form of tissue, whilst the liquid through which they are dispersed has lost its coagulating power. Thus is produced the *Suppurating* process; which may take-place either in a cavity thus excavated in the substance of a tissue or organ, or on a free surface. In either case, the surrounding tissues, which are less inflamed, and in which the vitality is impaired but not destroyed, become consolidated by a deposit of organizable fibrin, which prevents the infiltration of pus through their substance. If this should not occur, through a want of power to generate well-elaborated fibrin, the suppurating process extends itself rapidly, with the most calamitous results; the properties of pus being such as to produce a tendency to decomposition, both in the blood and in the solid tissues into the substance of which it may be carried.

633. Another consequence of Inflammation is *Ulceration*, which is a breach of surface caused by the same process as that which forms the cavity of an abscess,—namely, the degeneration of the inflamed tissue, and the removal of its particles, either by absorption, or by solution and ejection in pus. Many ulcers commence as abscesses near the surface, which at last come to open upon it; and others are preceded by inflammation of the superficial tissues, which die and are thrown-off, leaving a vacuity which may be subsequently increased by the extension of the degeneration to the

deeper parts. These may either die and be thrown-off *en masse*, constituting what is known as the 'sloughing ulcer,' or they may disintegrate more slowly, and may be dissolved in the discharge from the ulcerated surface. This discharge, when proceeding from a spreading ulcer, is usually of a thin ichorous quality, and has the power of exciting unhealthy action even in healthy parts to which it may be applied; and it is its change to what has been designated as 'laudable pus,' that indicates the cessation of the destructive, and the commencement of the reparative process (§ 636).

634. The state of *Gangrene*, which consists in the entire loss of vitality of the part, with a complete cessation of the circulation through it, is commonly regarded as a result of Inflammation, when this process occurs in its most intense form; but it may be more rightly considered as the ultimate consequence of the causes which produce Inflammation. For it is an essential part, as we have seen, of the condition of Inflammation, that the vitality of the affected tissues should be lowered; and thus there is in them always a tendency to death, which is most completely developed in Gangrene. We have a well-marked example of this complete destruction of the life of a part, by the intense operation of causes which when less potent occasion Inflammation, in the case of frost-bites produced by Cold; for this agent at the same time produces contraction of the blood-vessels and depression of the vital powers of the solid tissues, proceeding to the complete destruction of them; whilst in the parts adjoining those which are actually killed, the inflammatory state is developed, an effusion of fibrin being produced, which serves to plug-up the mouths of the vessels, and thus to prevent hemorrhage when the mortified part drops-off. Here we see that the violent action of cold completely destroys the vitality of the part most exposed to it; and this by its direct influence on the properties of the organized structure. No inflammation can take place in the part thus killed, because the vital processes are altogether brought to an end. But inflammation takes-place in the adjoining parts, which are less seriously affected; for the depression of their vital powers occasions the result already adverted-to, —namely, the production of an increased amount of fibrin in the blood, and an infiltration of this substance into their tissues. The same is the case with regard to the operation of other powerful agents; such as those which (like caustic potass, or sulphuric acid) destroy the vitality of the parts to which they are applied, by the chemical decomposition of their tissues. The Inflammatory process is set-up, not in the parts which are killed by the application, but in the surrounding tissues whose vitality has been simply depressed; and thus, when the *slough* or dead part is cast-out, there is a preparation for the prevention of hemorrhage and for the development of new tissue, in the superabundance of plastic materials in the neighbouring parts.

635. If, then, we limit the term Inflammation—as there seems reason to do—to that state in which there is a tendency to stagnated circulation with increased production of fibrin in the vessels of the part, we see that Gangrene cannot be a result of that process, which is one rather of reparation than of destruction. But Gangrene proceeds, where we can distinctly trace its causes, from the violent operation of the same agents as those which in a less degree produce Inflammation. And where this last process is not set-up at the line of demarcation between the living and the dead parts, Gangrene, like Suppuration, has a tendency to spread; the influence of the decay which is taking-place in one part, having a tendency to propagate itself to the adjoining tissues; and a constantly-extending destruction being thus produced.

636. We have now to speak of those *reparative* processes, by which the effects of disease or injuries are more or less perfectly recovered-from.—The healing of a simple wound may take-place by the direct adhesion of its walls, when they can be drawn closely together; but more frequently it is accomplished by the intermediation of a thin layer of 'coagulable lymph,' which may be thrown-out for the purpose of reparation, without the existence of inflammatory action. But the reparation of wounds in which there has been so great a loss of substance that neither direct nor indirect adhesion can take place, is accomplished by the gradual development of new tissue from the 'nucleated blastema' with which the cavity is first filled. This, however, may occur in two very different modes; and from the inquiries of Mr. Paget it appears that the determination of one or the other of them is chiefly dependent on the condition of the wound, as to seclusion from air, or exposure to it. When the reparative effusion is poured-out into a subcutaneous wound, the 'nucleated blastema' appears to be gradually developed into fibrous tissue without any loss, and usually with freedom from local inflammation (beyond what may be the immediate result of the injury), as well as from constitutional irritation. This process seems to take-place naturally in cold-blooded animals, even in superficial wounds; the contact of air not producing that disturbance of it, which this occasions in warm-blooded animals. And Nature frequently endeavours (so to speak) to bring it about in the superficial wounds of warm-blooded animals, by the formation of a large scab, which protects the exposed surface; but this happens much less frequently in the Human subject than it does among the lower animals, the unnatural conditions in which a large proportion of the more civilized races habitually live (especially deficient purity of the air, continual excess in diet, and the frequent abuse of stimulants), being obviously unfavourable to it. The application of *steam* to wounded surfaces has been found to favour the reparation by the most healthy process; and the formation of an artificial scab by means of resinous unguents has also

been practised with advantage. It is the duty of the Surgeon to endeavour to promote it by every means in his power; since it is the method of healing which is not merely the most desirable as regards its economy of nutritive material and freedom from constitutional irritation, but which most completely supplies the loss of substance, so that the cicatrix does not subsequently contract. The newly-formed fibrous tissue becomes vascular, by the extension of loops or arches from the adjacent capillaries, and of other loops from these; and subsequently other structures—such as bone, lymphatics, and nerves,—may be developed in it. True Cartilaginous tissue, and the higher form of Muscular fibre, however, seem never to be thus generated *de novo* in the new tissues of a repaired part; wounds of Cartilages and Muscles being united by simple fibrous texture.

637. In an open wound, on the other hand, which is healing by the process termed *Granulation*, the 'nucleated blastema' is rapidly developed into cells, amongst which vessels speedily extend themselves (Fig. 20); but the vitality of this tissue is very low, and that part of it which is exposed to the air passes into the condition of *pus*, its cells being either imperfectly developed from the first, or speedily undergoing degeneration. Thus there is a constant waste of plastic material, the amount of which, in the case of an extensive suppurating sore, must be a serious drain upon the system; whilst at the same time the local inflammation is greater, and gives-rise to more or less of constitutional disturbance; and the formation of new tissue is so much less complete, that by its subsequent degeneration and removal by absorption a contracted cicatrix is produced, which is different from the original texture. The new tissue is here produced by a metamorphosis of cells into fibres; and this change is taking-place in the deeper part of the granulation-structure, whilst the more superficial is degenerating into pus.—The difference between the two modes of reparation now described, is often one of life and death, especially in the case of large burns of the trunk in children; for it frequently happens that the patient sinks under the great constitutional disturbance occasioned by a large suppurating surface, although he may have survived the immediate shock of the injury.

638. If the plasma of the Blood, however, be not well elaborated, it does not possess its due organizability; and thus instead of being converted, either when effused as an Inflammatory product, or in the ordinary Nutritive process, into solid tissue proper to the part in which it is deposited, it is liberated from the vessels in a state which prevents any but a very imperfect structure from being developed by it, and which tends to very speedy degeneration. This is the condition of the *Tubercular* substance which is so often found to replace the proper tissue, especially in the lungs; being slowly deposited there by a sort of degradation of the regular

nutritive operations, and being effused in larger quantity when the inflammatory process is set-up. There is every degree of gradation between the *plastic* or *organizable* deposit of well-elaborated plasma, the *caco-plastic* or *imperfectly-organizable* matter of Tubercle, and the *aplastic* or *non-organizable* matter of Pus. The microscopic examination of tubercular deposits shows that they sometimes contain fully-developed cells and fibres, analogous to those of fibrinous exudations; but that more frequently the cells and fibres are imperfectly formed, and are accompanied by a large quantity of a granular substance which strongly resembles coagulated Albumen; and that in many cases, there is scarcely any trace of organization in the mass. The greatest degree of organization is found in the semi-transparent, miliary, grey, and tough yellow forms of Tubercle; the least in the opaque, crude, or yellow Tubercle.—It is the opinion of some eminent Pathologists, that Tubercular matter always possesses the *cellular* form in the first instance, but that it tends to undergo a rapid and complete degeneration.

639. The constitutional state which predisposes to this perversion of the ordinary nutritive operations, and which is known as the Tubercular Diathesis, may be the result of the continued operation of any causes that tend to depress the vital powers; such as insufficient nutrition, habitual exposure to cold and damp, protracted mental depression, &c.; or it may be derived from the operation of the same or other causes on the ancestors of the individual, being one of those disorders which has a peculiar tendency to become hereditary. The treatment must be directed to the invigoration of the system by good food, active exercise, pure air, warm clothing, and cheerful occupations; and by the due employment of those means at a sufficiently early period, many valuable lives may be saved, which would otherwise fall a sacrifice to Tubercular disease in the lungs or other important organs.—Much reason has lately presented itself for the belief, that a deficiency of appropriate *oleaginous* constituents in the food exerts a direct influence in the production of the Tubercular diathesis. This would appear to be indicated by the very marked benefit which has been derived, in the treatment of Pulmonary Consumption and other tubercular diseases, from the use of Cod-liver oil, or of other easily-assimilated fish-oils. And the same view is confirmed by the remarkable exemption of the Icelanders (whose diet is extremely oleaginous) from Tubercular diseases, notwithstanding that the general habits of the people would seem peculiarly favourable to their production.

640. There is another remarkable class of diseases, resulting from a disordered condition of the nutritive processes;—those, namely, of a *malignant* nature. We not unfrequently meet with abnorm growths of a fatty, cartilaginous, fibrous, or bony structure; which appear to originate in some perverted action of the part itself also

which have little tendency to reappear in the same part when they have been removed, still less to reappear in distant parts. But the various forms of Malignant or Cancerous disease are peculiar in this; that they are composed of cells, sometimes of a globular form (see Fig. 19), sometimes elongated or spindle-shaped, having a power of rapid multiplication, and not capable of changing into any kind of normal tissue. When a truly cancerous growth has once established itself in any part of the body, it may increase to an unlimited extent, obtaining its nourishment from the blood-vessels in its neighbourhood, and destroying the surrounding parts by its pressure, as well as by drawing-off their supply of aliment. When it has developed itself to a considerable degree in one part, it is very liable to make its appearance in others, especially when the original growth has been removed; and hence the judicious surgeon is disinclined to remove a Cancerous growth of any but the most limited kind, knowing that the disease is almost certain to reappear. There is a strong analogy between such Cancerous growths, and those low forms of Fungoid Vegetation which develope themselves in the interior of the higher Plants and even in Animal bodies; and in both cases, the disease may be propagated by inoculation from one individual to another. But still it appears probable that Cancerous disease, like tubercular, is of constitutional origin; and the peculiar tissue which characterizes it, is perhaps to be regarded simply as the manifestation of the presence of a morbid matter in the blood, which is thus removed from the circulating current; just as fatty matter is removed by an increased formation of Adipose tissue, or as the elements of the excretions are eliminated by an increased growth of the gland-cells of which they are the appropriate pabulum.

CHAPTER VIII.

OF RESPIRATION.

1. *Essential Nature and Conditions of the Respiratory Process.*

641. THE function of Respiration essentially consists in an interchange of oxygen and carbonic acid between the blood of the Animal and the surrounding medium; carbonic acid being given-out from the blood, and oxygen entering in its stead. It has been already noticed (§ 84) that this function is performed likewise by Plants; although, in consequence of their deriving a large part of their food from the atmosphere by a converse process (the absorption of carbon

and the liberation of oxygen) their true respiration is commonly overlooked. It may, therefore, be regarded as common to all Organized beings.—Every one is conscious, in his own person, of the imperative demand for the due performance of this operation. If the breath be purposely held for even a few seconds, a feeling of discomfort is experienced, which increases every moment, and at last prompts irresistibly to the respiratory movement. And if the admission of air to the lungs be in any way prevented, the respiratory movements are at first increased in energy, violent efforts being made to obtain the needed supply; these are succeeded by irregular convulsive actions, and at the same time insensibility comes-on; and within a short time all movement ceases, the circulation of the blood is suspended, and a stop is put to all the vital operations of the body. This state, which is termed *Asphyxia*, usually comes-on, in a warm-blooded animal, within ten minutes of the time when the respiration is completely checked; thus affording the most convincing proof of the importance of that function in the Animal economy. In many cold-blooded tribes, however, a much longer suspension may be borne with impunity; as also by warm-blooded animals, when the general activity of their functions is lowered in the state of *hybernation* (§ 121). We shall now inquire into the sources of the necessity for this interchange of oxygen and carbonic acid; and the mode in which the suspension of it acts upon the system at large.

642. All Organized bodies, as already explained, are liable to continual decay, even whilst they are most actively engaged in performing the actions of Life; and one of the chief products of that decay is carbonic acid. A large quantity of this gas is set-free during the decomposition of almost every kind of organized matter; the carbon of the substance being united with oxygen supplied by the air. Hence we find that the formation and liberation of carbonic acid goes-on with great rapidity after death, both in the Plant and in the Animal; and that it takes-place also, to a very great extent, in the period that often precedes the death of the body, during which a general decomposition of the tissues is occurring. Thus in Plants, as soon as they become unhealthy, the extrication of carbon in the form of carbonic acid takes-place in greater amount than its fixation from the carbonic acid of the atmosphere; and the same change normally takes-place during the period that immediately precedes the annual fall of the leaves, their tissue being no longer able to perform its proper functions, and giving-rise by its incipient decay to a large increase in the quantity of carbonic acid set-free. The same thing probably happens in the Animal body, during the progress of many diseases which are attended with an extraordinary tendency to decomposition in the solids and fluids; for in such cases the blood commonly exhibits an unusually dark hue, indicating that it has not been properly freed from the excessive

amount of carbonic acid which it has received from the tissues. It has not yet been accurately determined, however, whether there is an increase in the amount of carbonic acid actually thrown-off in such cases.

643. Hence the first object of the Respiratory process, being that which is common to all forms of Organized being, is to extricate from the body the Carbonic acid which is one of the products of the continual decomposition of its tissues. The softness of many of the tissues of Animals, and the large quantity of fluid contained in their bodies, render them more prone than Plants to this kind of decomposition; and in warm-blooded animals, the high temperature at which the fabric is usually maintained, adds considerably to the degree of this tendency; so that the *waste* of their tissues, from this cause alone, is as much greater than that of cold-blooded animals, as the latter is than that of Plants. But when perature of the Reptile is raised by external heat to the level of that of the Mammal, its need for respiration increases, owing to the augmented waste of its tissues. When, on the other hand, the warm-blooded Mammal is reduced in the state of hybernation to the level of the cold-blooded Reptile, the waste of its tissues diminishes to such an extent, as to require but a very small exertion of the respiratory process to get-rid of the carbonic acid which is one of its chief products. And in those animals which are capable of retaining their vitality when frozen (§ 136), or when their tissues are completely dried-up (§ 159), the decomposition is for the time entirely suspended, and consequently there is no carbonic acid to be set-free.

644. But another source of Carbonic acid to be set-free by the Respiratory process, and one which is peculiar to Animals, consists in the rapid changes which take-place in the Muscular and Nervous tissues, during the period of their activity. It has been already shown (§ 361), that there is strong reason to believe the waste or decomposition of the Muscular tissue to be in exact proportion to the degree in which it is exerted; every development of muscular force being accompanied by a change in the condition of a certain amount of tissue. In order that this change may take-place, the presence of Oxygen is essential; and one of the products of the union of oxygen with the elements of muscular fibre, is Carbonic acid. The same may probably be said of the Nervous tissue (§ 384). Hence it may be stated as a general principle, that the peculiar waste of the Muscular and Nervous substances, which is a condition of their functional activity, and which is altogether distinct from the general slow decay that is common to these tissues with others, is another source of the carbonic acid which is set-free from the animal body; and that the amount thus generated will consequently depend upon the degree in which these tissues are exercised. In animals which are chiefly made-up of the organs of

vegetative life, in whose bodies the nervous and muscular tissues form but a very small part, and in whose tranquil plant-like existence there is but very little demand upon the exercise of these structures, the quantity of carbonic acid thus liberated will be extremely small. On the other hand, in animals whose bodies are chiefly composed of muscle, and whose life is an almost ceaseless round of exertion, the quantity of carbonic acid thus liberated is very considerable.

645. We are enabled to trace the connection between the amount of muscular exertion, and the quantity of carbonic acid set-free in the act of respiration, in the class of Insects, better than in any other. They have no fixed temperature to maintain; and they are consequently not in the condition of warm-blooded animals, in which the quantity of carbonic acid set-free is kept-up to a more regular standard by the provision to be presently noticed. On the other hand, they are pre-eminent among all Animals, in regard to the energy of their muscular power in relation to the bulk of their bodies; and the waste of muscular tissue during their state of activity must therefore be very great. Thus a Humble Bee has been found to produce one-third of a cubic inch of carbonic acid in the course of a single hour, during which its whole body was in a state of constant movement, from the excitement consequent upon its capture; and yet during the whole twenty-four hours of the succeeding day, which it passed in a state of comparative rest, the quantity of carbonic acid generated by it was absolutely less.

646. Besides these sources of Carbonic acid, which are common to all animals, there is another which appears to be peculiar to the two highest classes, Birds and Mammals. These are capable of maintaining a constantly-elevated temperature, so long as they are supplied with a proper amount of appropriate food; and their power of doing so appears to depend upon the *direct* combination of certain elements of the food with the oxygen of the air, by a process analogous to combustion; these elements having been introduced into the blood for that purpose, but not having formed a part of any of the solid tissues of the body, unless they have been deposited in the form of fat. The nature of these substances has been already noticed (§ 431). It is quite clear that they cannot be applied in their original form, to the nutrition of the tissues that originate in protein-compounds; and it may be considered as certain that they undergo no such conversion within the body, as would adapt them to that purpose. The Liver seems to afford a channel by which some of the fatty matters are drawn-off from the blood; but even these seem to be in great part re-absorbed (§ 725), and to be thrown-off by the respiratory process.

647. The quantity of Carbonic acid that is generated directly from the elements of the food, seems to vary considerably in different animals, and in different states of the same individual. In the

Carnivorous tribes which spend the greater part of their time in a state of activity, it is probable that the quantity which is generated by the waste or metamorphosis of the tissues is sufficient for the maintenance of the required temperature, and that little or none of the carbonic acid set-free in respiration is derived from the direct combustion of the materials of the food. But in Herbivorous animals of comparatively inert habits, the amount of metamorphosis of tissue is far from being sufficient; and a large part of their food, consisting as it does of substances that cannot be applied to the nutrition of the tissues, is made to enter into direct combination with the oxygen of the air, and thus to compensate for the deficiency. In Man and other animals, which can sustain considerable variations of climate, and can adapt themselves to a great diversity of habits, the quantity of carbonic acid formed by the direct combination of the elements of the food with the oxygen of the air, will differ extremely under different circumstances. It will serve as the *complement* of that which is formed in other ways; so that it will diminish with the increase, and will increase with the diminution, of muscular activity. On the other hand, it will vary in accordance with the external temperature; increasing with its diminution, as more heat must then be generated; and diminishing with its increase. —In all cases, if a sufficient supply of food be not furnished, the store of fat is drawn-upon; and if this be exhausted, the animal dies of cold (§ 117).

648. To recapitulate, then; the sources of Carbonic acid in the Animal body are threefold.—1. The continual decay of the tissues, which is common to all organized bodies, which is diminished by cold and dryness, and increased by warmth and moisture, which takes-place with increased rapidity at the approach of death, whether this affect the body at large or only an individual part, and which goes-on unchecked when the actions of nutrition have ceased altogether:—2. The metamorphosis which is peculiar to the Nervous and Muscular tissues, which is the very condition of their activity, and which, therefore, bears a direct relation to the degree in which they are exerted:—3. The direct conversion of the carbon of the food into carbonic acid, which is peculiar to warm-blooded animals, and which seems to vary in quantity in accordance with the amount of heat to be generated.

649. Now the function of Respiration has for its object, not merely to extricate the Carbonic acid which is generated in the system, but likewise to introduce the Oxygen which is required for the formation of that carbonic acid, as well as for other purposes. Hence it is not enough that the carbonic acid should be removed; for this may be accomplished by causing an animal to breathe an atmosphere which contains no oxygen. Any cold-blooded animal, such as a Frog or a Snail, may be kept in hydrogen or nitrogen for several hours or even days; and will give-out, during that time,

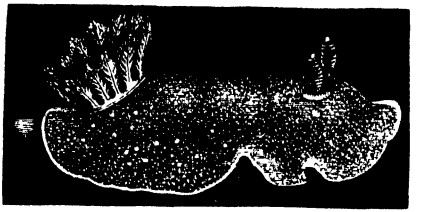
an amount of carbonic acid nearly as great as if respiring atmospheric air. But the continued production of carbonic acid must have a limit, occasioned by the want of oxygen may be freely afforded; and yet the presence of even amount of carbonic acid in the surrounding atmosphere (in a to that which is normally present in it, § 81) will impede the cation of that substance from the blood; and if the excess be considerable, the carbonic acid will not be set-free at all; so that the same injurious results follow as if respiration were altogether prevented from taking-place.

650. These two changes are accomplished by the very same act; advantage being taken of the property of 'mutual diffusion,' which is common to all gaseous substances that do not unite chemically with one another. In virtue of this property, Hydrogen, the lightest of gases, and Carbonic acid, one of the heaviest, when introduced into the same vessel, will be found in a short time to have uniformly mixed, notwithstanding the difference of their specific gravities, which are as 1 to 22. Now this intermixture will take-place when the two gases are separated by a porous septum; each gas passing towards the other, by an action resembling the Endosmose and Exosmose of liquids (§ 491). And it may also take-place when one of the gases is diffused through a liquid, provided that the other gas is likewise capable of being absorbed by the liquid. In this manner, as already mentioned, the surface of venous blood inclosed in a bladder will be made to exhibit the arterial hue, by suspending the bladder in an atmosphere of oxygen; for the carbonic acid of the blood and the surrounding oxygen will overcome by their mutual attraction the obstacle interposed by the bladder; and the former will be lifted-out, so to speak, and will be replaced by the latter. It has been found by experiment, that the free carbonic acid diffused through blood may be more completely extricated from the liquid by exposing it to hydrogen, than by placing it under the vacuum of an air-pump; for in the latter case there is nothing to replace it, and the attraction between the gas and the liquid tends to resist the exhausting influence of the vacuum; whilst in the former, the blood receives one gas in exchange for the other, so that the whole force of the tendency to mutual diffusion is exercised in lifting-out the carbonic acid.

651. The immediate purpose of the organs of Respiration, then, —whatever may be the variety in their form,—is this; to expose the blood to the air in a state of such minute division as to present a very extended surface, a thin membrane only being interposed between them. For this purpose we find a certain organ, or set of organs, specially set-apart in all the higher animals; and this is formed by a prolongation of the general surface, either externally or internally, according to the mode in which the respiration

is accomplished. Thus in Fishes and aquatic Molluska, the blood is aerated by exposure, not directly to the atmosphere, but to the air which is dissolved in the water they inhabit; and the respiratory apparatus is formed in them of an extension of the *external* surface, at a particular part, into innumerable delicate fringe-like processes, the *gills* (Fig. 106); every division of which contains a net-work of

Fig. 106.*



blood-vessels (Fig. 110): so that the amount of blood which is exposed to the surrounding medium at any one time, is collectively very great, although the quantity contained in each gill-filament is very minute. In all the air-breathing Vertebrata, on the other hand, the blood is exposed to the atmosphere through the medium of an *internal* membranous prolongation, which is continuous with the mucous membrane lining the mouth and nostrils; this forms a pair of sacs termed *lungs*, communicating with the back of the mouth by means of a tube called the *trachea* or windpipe, through which air is freely admitted to the cavities thus formed (Fig. 111). The blood is minutely distributed on the walls of these sacs by a close network of capillary vessels (Fig. 112); and this not only on the external walls, but also on numerous partitions by which the cavities are subdivided with more or less minuteness, so as greatly to extend the vascular surface.

652. Such is the essential nature of the Respiratory apparatus; but in order that it may be carried into that vigorous operation which is required in the higher classes of animals, various supplementary arrangements are made for the purpose of promoting the due influence of the air upon the blood. In the first place, the capillary vessels of the respiratory surface are connected with arterial trunks, which issue immediately from the heart, and which thus convey a constant stream of blood from that organ; whilst they give origin to venous trunks, which terminate directly in the

* *Doris Johnstoni*, a Nudibranchiate Gasteropod, showing the tuft of external gills.

heart, and which are ready to convey back to it the blood that has undergone aeration. Thus by the energetic action of the heart, and by the force generated in the capillaries of the lungs (§ 598), a constant renewal is effected in the blood which is exposed to the air through the medium of these organs. On the other hand, the renewal of the blood would be useless, unless a fresh supply of air were continually being introduced, and that which had been vitiated by the loss of its oxygen and the admixture of carbonic acid were removed; and this is effected by a series of muscular movements, which are adapted for the alternate expulsion of the vitiated air from the lungs, and for the introduction of a fresh supply of pure air from the atmosphere. These movements are kept-up by a certain part of the nervous system; but they are not dependent upon any exertion of the will, for they continue during profound sleep, and in other states in which even consciousness is altogether suspended.

2. *Different forms of the Respiratory apparatus in the lower Animals.*

653. Before proceeding to consider, in more detail, the structure and actions of the respiratory apparatus in Man, we may advantageously glance at the mode in which this function is effected in the lower animals.—In the lowest and simplest, all of which are inhabitants of the water, we do not find any special apparatus for the aeration of the fluids of the body, this being accomplished by the exposure of them to the surrounding medium, through the thin integument; and the interchange of the layer of water (holding air in solution) in contact with the aerating surface, is effected either by the general movements of the body, or by the action of *cilia* (§ 234) which produce the currents necessary for this purpose. Not unfrequently, the internal surfaces—such as the walls of the stomach and of other cavities—seem as much concerned in this function as the external, or even more so; these cavities being distended with water taken-in through the mouth, and this water being frequently renewed by the ejection of that which has been vitiated, and by the introduction of a fresh supply. This is the case in the Sea Anemone, for example, and in many other Polypes; and there are certain higher forms of the same class, in which there is a great dilatation of the pharynx, which seems peculiarly destined for the aeration of the fluids,—being filled with water, and then suddenly emptied, at tolerably regular intervals.

654. In the various classes of the Molluscous sub-kingdom, we find the respiration provided-for by the adaptation of distinct organs for the purpose. As most of the animals of this group are inhabitants of the water, the respiration is usually carried-on by means of gills, rather than by any organ resembling a lung. The latter is

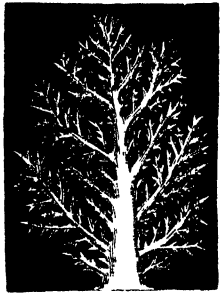
found, however, in a few species, such as the Snail, Slug, and other terrestrial air-breathing Mollusks; and usually consists of a simple cavity, situated in the back, communicating directly with the air through an aperture in the skin, and having its walls covered with a minute network of blood-vessels. The form and position of the gills differ extremely in the several classes of Molluscous animals. In the lowest, the respiratory surface is formed by a dilatation of the Pharynx; but sometimes, instead of surrounding a large cavity, it forms a special riband-like fold of membrane, passing from one end of it to the other, on which the blood is minutely distributed. In this group of animals, there is a regular system of canals for the conveyance of the blood; but these, in many parts of the system, and especially on the respiratory membrane, do not seem to be furnished with distinct walls, and are rather mere channels excavated in the tissues. And the circulation is liable to a continual change in its direction, the blood being sometimes transmitted to the respiratory surface *before* it proceeds to the body, and sometimes *after* it has traversed the other tissues (§ 557). The water in contact with the respiratory surface is continually renewed by the action of the cilia with which it is thickly covered.

655. In certain of the Mollusks inhabiting bivalve shells, we find that the surface of the double fold of the loose skin or 'mantle' that lines the valves, is the special organ of respiration; the external water having free access to this by the separation of the folds of the mantle along the edges of the valve. But in most bivalve Mollusks, this surface of the mantle is doubled (as it were) into four riband-like folds, which are delicately fringed at their edges, and which have, in fact, the same essential structure as the gills of higher animals (§ 663). To these the blood is transmitted, when it has been rendered venous by traversing the vessels of the body generally: and in these it is exposed, through a surface which is greatly extended by the minute division of the fringes, to the action of water introduced from without, and constantly renewed by ciliary action. In many of these animals, as in the common Oyster, the two lobes of the mantle are so completely separated that the water can still enter freely between the valves; but in general they are more or less united, so that the cavity in which the gills lie is partially closed. There is always a provision, however, for the free access of water from without, by means of two apertures, one for its entrance and the other for its ejection; and in certain species which burrow deeply in sand or mud, these apertures are furnished with long tubes, or *siphons*, which convey the water from nearer the entrance of the burrow, and carry it thither again. In these also, a continual flow of water over the respiratory surface is maintained by the vibration of the cilia with which they are clothed.

656. The position of the gills in the Mollusca of higher organiza-

tion, is extremely variable. Sometimes they are disposed upon the external surface of the body, and form delicate leaf-like or arborescent appendages (Fig. 107); whilst in other cases they are enclosed in a special cavity or gill-chamber, to which water is freely admitted from without; a continual interchange being provided-for, either by ciliary action, or by muscular movements specially adapted for the purpose. The blood is conveyed to them, after having become venous in traversing the capillaries of the general system, by means of large channels and sinuses excavated in the several parts of the body (§ 556); and after being aerated in the gills, it returns to the heart, to be again conveyed to the system. In the Cuttle-fish tribe, there are supplementary hearts at the origin of the branchial arteries or vessels that distribute blood to the gills; and these have evidently for their purpose to render the respiratory circulation more energetic, and thus to increase the aeration of the blood in the degree required for the vigorous habits of these animals, which present a remarkable contrast to the sluggish inert character of the Mollusca in general.—In these classes, taken as a whole, the respiration is low in its amount. The blood contains no *red* corpuscles; and the change in its composition which is effected by the air, would seem to be confined, therefore, to the fluid plasma or liquor sanguinis. And as it is not exposed directly to the air, except in a few species, but to the air contained in the water inhabited by the animals, this change cannot be very energetically performed. But as the life of these animals is chiefly vegetative,—as their movements, except in the higher classes, are few and feeble,—and as they maintain no independent heat,—there is but little need of that interchange which it is the object of the respiratory process to effect; and they can sustain the complete suspension of it for a long time.

Fig. 107.*



657. Among many of the Articulated tribes, the respiration is carried-on upon a similar plan. In some of the lowest, such as the Tapeworm of the intestinal canal, there is no special provision for the aeration of the fluids; the soft integument permitting the extrication of carbonic acid and imbibition of oxygen, in the required

* One of the arborescent processes, forming the Gills of *Doris Johnstoni*, separated and enlarged.

degree. This degree is but very small, however; the life of these animals being almost purely vegetative. In the Marine Worms, which constitute a numerous and interesting group, endowed with considerable locomotive powers, and leading a life of almost constant activity, there is, on the other hand, a special provision for this function; the circulating fluid* being transmitted in its course to a series of gill-tufts, which are composed of a delicate membrane prolonged from the external surface of the body, and which sometimes have the form of branching trees, and sometimes of delicate brushes made-up of a bundle of distinct filaments. In either case the filaments are traversed by blood-vessels, and are adapted to bring the blood into close relation with the surrounding water; and the continual interchange of the latter is provided-for by the restless movements of the body as well as by ciliary action. The tufts are sometimes arranged along every segment of the body, and their multiplication prevents them from individually attaining any considerable size: in other cases, they are disposed at intervals, and they are then larger but less numerous. Their most beautiful development is where they are present on the head only, the rest of the body being enclosed in a shelly or sandy tube, as in the *Serpulæ* and *Terebellæ;* for they then present the appearance of a flower, endowed with the most brilliant and delicate hues. In many animals of this group, there is a small supplementary heart at the base of every one of the vessels that distribute the blood to the gills; and this is obviously designed to aid in the respiratory circulation, for which the feeble action of the dorsal vessel would not furnish sufficient power (§ 552).

658. The higher Articulated classes are, for the most part, adapted to atmospheric respiration according to the plan to be presently explained; but there is one class, that of Crustacea, whose respiration is still carried-on through the medium of water. In the lowest forms of this group, there is no special respiratory apparatus; the general surface being soft enough to admit of the required aeration of the fluids through its own substance, and the animal functions being performed with so little activity, that a very small amount of interchange is required. In the higher orders, however, whose bodies are encased within a hard envelope, we find

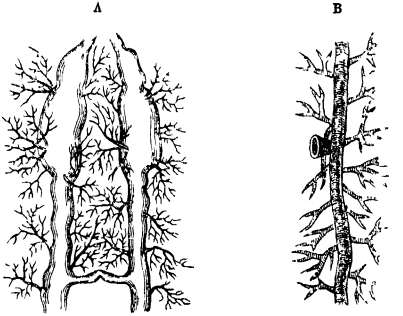
* It would seem as if, in the Annelida, the *respiratory* fluid were distinct from the *nutritive* fluid. The former is red, but without corpuscles, and circulates in a regular system of vessels with definite walls. The latter is colourless and corpusculated; and moves in the general cavity of the body and in prolongations from it. In many of the higher Annelida, such as the *Terebella*, there is distinct provision for the aeration of both these fluids; the red blood (?) being transmitted through regular gills, and the white through the numerous tentacular filaments. In others, however, the red fluid alone is transmitted through any organs that can be regarded as specially respiratory; whilst in the inferior forms of the class, the red fluid and its system of vessels are altogether wanting, and there is only the colourless corpusculated fluid to be submitted to aeration.

external gills, like those of many Mollusks; and these are attached to the most moveable parts of the body,—one or more pairs of legs being in some instances kept in constant agitation, for the purpose of producing currents in the surrounding fluid, that may serve for the aeration of the blood. In the Crab-tribe, which constitutes the highest family of this class, the gills are themselves enclosed within a cavity, formed by a sort of doubling of the hard integument of the under side of the body; and a constant stream of water is maintained through this, by means of a peculiar valve situated in the exit-pipe, the continual movement of which causes a regular stream of water to issue from the gill-chamber, and thus occasions the entrance of a constantly-fresh supply. In these, also, we find a dilatation whose walls seem to have contractile powers, at the commencement of each artery that distributes the blood to the gills; and this collects the venous blood from the various channels in which it has meandered through the body. It is by the enclosure of the gills within a cavity, and by the consequent protection of them from the drying influence of the air (which would prevent their function from being duly performed), that Crabs and other allied species are enabled to live for a considerable time out of water; and the Land-Crabs, as they are termed, are adapted to spend the greater part of their lives at a distance from the sea, by means of a special glandular apparatus within the gill-cavity, which secretes a fluid that preserves the surface of the gills in the moist condition requisite for the aeration of the blood through its membrane. Thus the Land-Crabs are air-breathing animals (except at certain seasons when they frequent the sea-shores), although they breathe by gills.

659. In Insects and other proper air-breathing Articulata, however, the character of the respiratory apparatus is very different. The transition from one form to the other is effected through such animals as the Leech and the Earthworm, which seem able to live almost equally well in air or water, and whose respiration appears to be carried-on chiefly, if not entirely, through the medium of the external surface alone. These animals are furnished with a series of small sacs, disposed at regular intervals along each side of the body, and opening by a row of pores which are termed *spiracles* or *stigmata;* but these sacculi do not seem to participate in the respiratory function, their office being rather to secrete a protective mucus. But in the Myriapods, these sacculi are respiratory organs, and communicate more or less freely with each other. And in Insects, the spiracles, instead of forming the entrances to so many distinct sacs, open into a pair of large tubes, one of which traverses the body on either side along its whole length. These tubes, termed *tracheæ*, have many communications with each other across the body; and they branch-out into innumerable prolongations, the ultimate ramifications of which are distributed to every portion of the system. They occasionally present dilatations of considerable

(Fig. 108, A); especially in the thoracic region of the body of those insects which are endowed with great powers of flight. These dilatations or air-sacs appear destined to serve as reservoirs of air during the time that the insect is upon the wing, its spiracles being then partially closed; and they may also be useful in diminishing the specific gravity of the body. The air-tubes are prevented from having their cavity obliterated through the pressure of the surrounding parts, by means of an elastic spiral fibre; which winds round them, between their outer and inner membrane, from one extremity to the other (Fig. 108, B); and which answers the

Fig. 108.*



purpose of the cartilaginous rings and plates in the trachea and bronchi of air-breathing Vertebrata.

660. In this manner, the air that is introduced through the spiracles is carried into every part of the body, and is brought into immediate relation with the tissues to be aerated; so that the carbonic acid which they set-free is communicated at once to the atmosphere, instead of being taken-up by the blood; and the oxygen they require is imbibed in the same manner. And thus we see how the respiration of this interesting class, which is unequalled for its energy when the body is in a state of activity, is provided-for without an active circulation of blood and without the presence of red corpuscles,—which elsewhere seem to be essential conditions of the interchange of oxygen and carbonic acid between the air and the tissues, wherever this takes-place to any great extent.

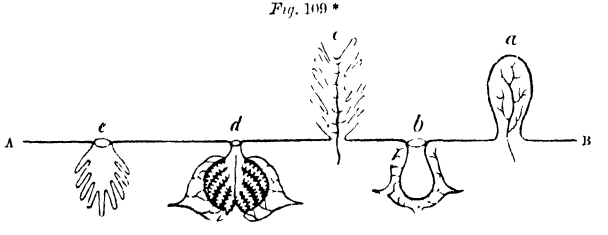
661. In the Spider tribe, we return to a more concentrated form

* The respiratory apparatus of Insects:—A, air-vesicles and part of tracheal tube of *Scolia hortorum:* B, portion of one of the great longitudinal trunks of its system of tracheæ; C, blood-corpuscles of *Carabus auratus*, with one of its spiracles.

of the respiratory apparatus; but, notwithstanding that it is limited within much narrower dimensions externally, it exposes a very large amount of surface on its interior. It consists of a series of sacs, much less numerous than in the lower Articulata, and not communicating with each other. Their lining membrane, however, is doubled into a series of folds, which lie in proximity with each other like the leaves of a book, and which thus present a very extensive surface within a very small space. Over this surface, the blood is distributed in a minute capillary network; and thus it comes into immediate relation with the air, which is received into the cavity through its aperture or spiracle. The alternate admission and expulsion of air seem to be provided-for, as in Insects, by movements of the body, which first empty the cavities or air-tubes by compression, and then allow them to be re-filled by their own elasticity, the pressure being relaxed. The respiratory cavities in the Spider-tribe have received the name of *pulmonary branchiæ;* from their analogy, on the one hand, with the lungs of higher animals, and, on the other, with the branchial sac or gill-cavity of the higher Crustacea, the gills in which are formed by prolongations of the lining membrane, corresponding with the leaf-like folds in the air-cavities of the Spider-tribe.

662. The accompanying diagram will give an idea of the relations of these different forms of the respiratory apparatus, both amongst themselves, and with that of Vertebrata. Let the line A B repre-

Fig. 109 *



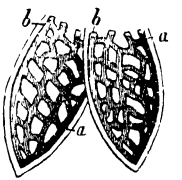
sent the general surface of the animal, the continuations of that line on its upper side being its *external* prolongations, and those below its *internal* prolongations or reflections. Now at *a* is seen the character of the simple foliaceous or leaf-like gill, such as is found in the lower aquatic animals; presenting merely a flat expanded surface in contact with the water, over which the blood may be distributed. At *b* is shown a correspondingly-simple inversion,

* Diagram illustrating different forms of the Respiratory apparatus:—*a*, simple leaf-like gill; *b*, simple respiratory sac, *c*, divided gill, *d*, divided sac; *e*, pulmonary branchia.

such as that which forms the respiratory sac of the Leech, having the blood-vessels distributed upon its walls. A higher form of the gill, such as is found in Fishes and in the higher aquatic Invertebrata, is seen at *c;* the surface being greatly extended by subdivision into minute filaments. A more complex form of the pulmonary apparatus, such as is found in the higher Vertebrata, is shown at *d;* the blood being distributed, not merely to its outer walls, but to the minute partitions which subdivide its cavity into cells. And at *e* is represented the respiratory organ of the Spider-tribe, which bears an obvious resemblance to the lung of the Vertebrated animal, shown at *d;* whilst it is evidently as nearly allied to the gill shown at *c*, provided this be imagined to be sunk within a cavity formed by a depression of the external surface, instead of projecting beyond it.—Thus we see how very close is the real resemblance between all the forms of the respiratory apparatus, however unlike each other they may at first sight appear to be.

663. The gills of Fishes correspond with those of the higher Mollusca in all essential particulars; but they are more largely developed in proportion to the size of the body, and they are placed in a situation that enables them to receive a more regular and constantly-changed supply, both of blood and of water. The gills are suspended to bony or cartilaginous arches, of which three, four, or more, are fixed on either side of the neck; and their fringes hang loosely within a cavity, which communicates on the one hand with the mouth, and on the other with the exterior of the body. The mechanism of respiration is very complex in these animals; and is evidently adapted to produce the most effectual aeration possible. The mouth is first distended with water; and its muscles are then thrown into contraction, in such a manner as to expel the water through the aperture on either side of the pharynx, into the gill-cavity. At the same time, the bony arches are lifted and separated from each other, by the action of muscles especially adapted to this purpose; so that the gill-fringes may hang freely, and may present no obstacle to the flow of the water between them. When they have been thus bathed with the aerating liquid, and their blood has undergone the necessary change, the water is expelled through the outward aperture on each side of the back of the neck; which

Fig. 110.*



* Capillary network of a pair of leaflets of the Gills of the Eel:—*a*, *a*, branches of the branchial artery conveying venous blood; *b*, *b*, branches of the branchial vein, returning aerated blood. The disappearance of the dark shading in the network, as it traverses the gill, is designed to indicate the change in the character of the blood, as it passes from one side to the other.

is furnished with a large flap or valvular cover, termed the operculum. In some of the cartilaginous Fishes, each branchial arch is inclosed in a separate cavity; which communicates on the inner side with the pharynx by an orifice peculiar to itself, and by another orifice with the external surface. Thus there is a series of external openings, instead of a single one, on each side of the neck; and these sometimes amount to six or seven, as in the Lamprey, reminding us of the spiracles of Articulated animals; whilst there is a corresponding series of internal openings into the pharynx on either side, or into a tube that communicates with it.

664. It is well known that most Fishes speedily die when removed from the water; and it can be easily shown that the deficient aeration of the blood is the immediate cause of their death. But as it might have been expected that the atmosphere would exert a much more energetic influence upon the blood contained in the gills, than that which is exercised by the air contained in the water, the question naturally arises how this deficient aeration comes to pass. It is chiefly due to the two following causes;—the drying-up of the membrane of the gills themselves, where it is exposed to the air, so that the aeration of the blood is impeded;—and the flapping-together of the filaments of the gills, which no longer hang loosely and apart, but adhere in such a manner as to prevent the exposure of the greater portion of their surface to the air. Those fishes can live longest out of water, in which the external gill-openings are very small, so that the gill-cavity may be kept full of fluid; and there are certain species which are provided, like the Land-crab, with a particular apparatus for keeping the gills moist, and which perform long migrations over land in search of food, even (it is said) ascending trees. These are exceptions to the general rule.

665. The respiration of Fishes is much more energetic than that of any of the lower aquatic animals; and this is partly due to the great extension of the surface of the gills, partly to the provision just explained for maintaining a constant flow of fresh water over their surface, and partly to the position of the heart at the base of the main trunk that conveys the blood to the gills (§ 558), by which the regular propulsion of that fluid through these organs is secured. Their blood, too, is furnished with red corpuscles, which give important aid in conveying oxygen from the gills to the remote tissues of the body, and in returning the carbonic acid to be excreted. The proportion of these varies considerably, in the different species of the class, being very small in those that approach most nearly to the Invertebrata; and there is even an entire absence of them in one remarkable fish, the Amphioxus or Lancelot; whilst they are present in large numbers in the blood of certain Fishes, which have great muscular activity and can maintain a high independent temperature.

666. It would seem, however, that not even this high amount of respiration is always sufficient for Fishes which live in small collections of water, where their temperature is liable to be greatly augmented by the heat of summer; under which condition there is an increased proneness to disintegration in their tissues, and a corresponding necessity for the extrication of carbonic acid and for the absorption of oxygen. Many fresh-water fishes, under such circumstances, may be seen to come to the surface and to *swallow* air; and it would seem as if the interior of the intestinal canal then served the purpose of a respiratory surface, the air being expelled from the anus deprived of a large part of its oxygen and highly charged with carbonic acid.

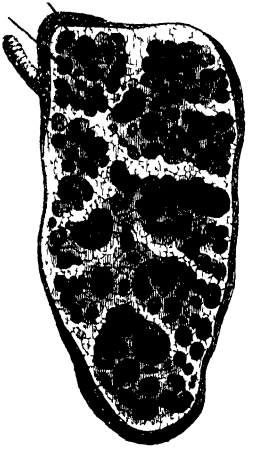
667. In addition to their apparatus for aquatic respiration, many Fishes are provided, in their *air-bladder*, with the rudiments of the air-breathing apparatus of higher animals; although it is only in certain species which approach Reptiles in their general organization, that this really affords any aid in the aeration of the blood. The air-bladder in its simplest condition is entirely closed; and it is then obviously incapable of taking any share in the respiratory function, although it seems to be an organ of some importance to the animal, in regulating its specific gravity and thus altering its position in the water. In other cases, it communicates with the intestinal tube by a short wide canal, termed the *ductus pneumaticus;* and this may serve to admit air, which is taken into the alimentary tube by the process of swallowing just mentioned. In the Reptilian Fishes just adverted-to, the air-bladder forms a *double* sac, which is evidently the representative of the double lung of the air-breathing Vertebrata; and it communicates with the back of the mouth by a regular trachea or wind-pipe, which has a muscular valve at its commencement, serving to open or to close its orifice. Some of these fishes are able to live for a considerable time out of water, their respiration being maintained by these rudimentary lungs; and they can also make a hissing sound, by the expulsion of the air contained in the air-sacs through the narrow glottis or entrance to the trachea.

668. The condition of the Respiratory apparatus, and the mode in which the function is performed, in the class of Reptiles, are peculiarly interesting; as it is in this class that we first meet with the complete adaptation of the Vertebrated structure to the aeration of the blood by the direct influence of the atmosphere. Their general habits of life require but a very feeble amount of aeration, especially at moderate temperatures; their muscular and nervous systems being usually exercised in a very low degree, their movements being sluggish, and their perceptions obtuse. In fact, they may be considered, on the whole, as the most vegetative of all Vertebrated animals. In accordance with this character, the lungs are so constructed as not to expose any very

large amount of blood to the air at any one time; and, as we have already seen (§ 563), only a portion of the stream of the circulation is diverted to the lungs; the main current being sent to the system with only that amount of aeration, which it has derived from the admixture of the portion of blood that has been aerated in the lungs, with the venous current that has last been returned from the system.

669. The lungs of Reptiles are, for the most part, capacious sacs, occupying a considerable part of the cavity of the trunk; but they are very slightly subdivided, so that the amount of surface they can expose is really small. Where any subdivision exists, it is usually at the upper extremity of the lung, near the point of entrance of the bronchial tube; and where there is no actual subdivision of the cavity, we usually find that its surface is extended in this situation, by the formation of a number of little depressions or pouches in its walls, upon which the blood-vessels are minutely distributed. The greatest amount of subdivision is seen in the lungs of the Turtle tribe; but even in these, the partitions scarcely form a complete division at any part of the lungs; and the ultimate air-cells are of very large size (Fig. 111). The air-sacs of Reptiles are not filled, like those of Mammalia, by an act of inspiration, but by a process of swallowing, which is comparatively tedious; and from the small proportion which the aerating surface bears to the amount of air thus received into the cavity, one inflation of the air-sacs lasts for a considerable time. When the replacement of oxygen by carbonic acid has proceeded to an extent that renders the air no longer fit to remain in the lungs, these cavities are emptied by pressure exercised upon them by the muscles of the trunk; and the slow exit of the air through the narrow glottis is accompanied by a prolonged hissing sound, which is the only sort of voice that is possessed by the greater part of the Reptile class. The lungs are again filled by the swallowing-process; and all goes-on as before.

Fig. 111.*



* Section of the Lung of the Turtle.

670. Now in the Frog tribe, which forms the lowest order of Reptiles (and which is sometimes ranked as a distinct class, under the title of Amphibia), the respiration during the early or *tadpole* state is aquatic; being carried-on by means of gills, and conducted exactly upon the plan of that of Fishes. The lungs are not developed until a period long subsequent to the animal's emersion from the egg; and as soon as they are ready to come into play, an alteration begins to take-place in the circulating system, by which the current of blood is diverted towards them, and away from the gills (§ 562). This change takes-place to its full extent in the Frog, Toad, Newt, and their allies; which henceforth have a respiration and a circulation exactly analogous to that of Reptiles in general; but it is checked in the Proteus, Siren, and other species, which form the *perennibranchiate* group,—so called from the persistent character of their gills, which still remain in action, the lungs never being sufficiently developed to maintain the respiration by themselves. The curious influence which Light possesses on this metamorphosis, has been already referred-to (§ 95).

671. This order *Batrachia* is further distinguished from other Reptiles, even when the metamorphosis is complete, by the softness and nakedness of the skin, which is destitute of the scales and horny plates that cover it in the Lizards, Serpents, and Tortoises. The skin of the Frog tribe is a very important organ of respiration, being richly supplied with blood-vessels, and exposing their contents to the influence of the air under circumstances nearly as favourable as those afforded by the imperfectly-developed lungs of these animals. Thus a Frog from which the lungs have been removed, will live for a considerable time at a moderate temperature, if its skin be freely exposed to a moist air; for in consequence of the peculiar mode in which the circulation is carried-on in these animals (§ 561), the interruption to the flow of blood through the lungs does not (as in the higher classes) produce a stagnation of the general current through the body; and the blood receives, in its course through the skin, a sufficient amount of aeration for the support of life. Indeed at a low temperature, the influence of water on the skin is sufficient (by means of the air included in the liquid) to remove the small amount of carbonic acid then ready for excretion, and to supply the requisite amount of oxygen; and Frogs may thus live beneath the water for any length of time, without coming to the surface to breathe. But with the rise of the temperature of their bodies, their blood requires a higher degree of aeration; and they then come to the surface to take-in air by the mouth, which aerates the blood through the lungs. It appears that, during the heat of summer, the pulmonary respiration, and the influence of the water on the skin, are not sufficient; as it is found that Frogs die if they be confined to the water under such circumstances,—their natural habit being to quit the water at

such times, so that the air may exert its full influence on their skin as well as on their lungs. They do not, however, quit the neighbourhood of water, and soon die if exposed to a dry atmosphere; for if the skin become dry, its aerating function can be no longer performed. The same result happens, if the passage of gases through the skin be impeded by smearing it over with any unctuous substance. We shall presently find reason to believe that this cutaneous respiration is a very important part of the function even in Man and the Mammalia.

672. The class of Birds presents a most striking contrast to that of Reptiles, in regard to the energy of the respiratory function, and the extent of the apparatus destined to its performance. The air-cells are considerably diminished in size, so that the extent of surface over which they expose the blood to the air is greatly increased; and there even seems reason to believe, that the air comes into direct contact with the vessels of the very close capillary plexus which intervenes between the air-cells. But the subdivision of the lungs is not carried to the same degree of minuteness as it is in Mammalia; and the required extent of surface would not be afforded by the lungs alone. In addition to these organs, we find large air-sacs communicating with them, disposed in different parts of the body,—such as the abdominal cavity, the interspaces among the muscles, the spaces between the muscles and the skin, &c. These very greatly increase the respiratory surface; their lining membrane being extremely vascular, and adapted to expose the blood to the influence of the air. In most Birds, the bones themselves are hollow; and the lining membrane of their cavities serves as an additional aerating surface, the air being introduced into the interior of the bones, by canals that communicate directly with the lungs. So free is this communication, that the respiration has been known to be maintained through the fractured humerus of an Albatross, when an attempt was made to destroy the bird by compressing its trachea. Thus the respiratory surface is extended into the remoter parts of the system, very much as in Insects; and the hollowness of the bones, together with the presence of numerous air-sacs in different parts of the body, contribute to diminish its specific gravity. The large quantity of air thus included in different portions of the frame, also serves, like that contained in the air-sacs of Insects, as a reservoir for the supply of the principal aerating organs during active flight, when the respiratory movements are less free.

673. The mechanism of Respiration in Birds is very different from that which produces the respiratory movements in Mammalia. The cavities of the chest and thorax are not yet separated by a diaphragm, except in a very small number of species that approach most nearly to the next class. But, on the other hand, the whole cavity of the trunk is more completely enclosed in a bony casing;

the ribs being connected with the sternum by osseous prolongations from the latter, instead of by cartilages; and the sternum itself being so largely developed, as to cover almost the entire front of the body. Now the natural condition of this bony framework is such, that when no pressure is made upon it, the cavity it encloses is in a state of distension; and the state of emptiness can only be produced by a forcible compression of the framework, through an exertion of muscular power. The lungs, instead of being freely suspended in the cavity of the chest, as in Mammalia, are attached to the ribs; and their own tissue is endowed with a degree of elasticity, which causes them to dilate when they are permitted to do so. In the state of distension, therefore, which is natural to the cavity of the trunk, the lungs are expanded and fill themselves with air which they draw-in through the trachea; and this condition they retain, until, by the action of the external muscles upon the bony framework, the cavity of the trunk is diminished, and the air is expelled from the lungs and air-sacs, which are again filled as soon as the pressure is taken-off.—As the air-sacs chiefly communicate with the part of the lungs that is most distant from the trachea, the air has to traverse the whole extent of those last organs, both when it is being drawn into the air-sacs, and when it is being expelled from them; so that it is made to serve for the aeration of the blood in the most effectual manner.

674. Thus, although the respiratory apparatus of Birds does not possess the highly-concentrated development which we shall find it to present in Mammals, it serves, by the extension of the aerating surface through the body, to bring the air and the blood into most intimate relation; and the energy of the function is further provided-for by the mode in which the pulmonary circulation is carried-on (a distinct heart, as it were, being provided for it, § 564), as well as by the arrangement of the blood-vessels, which transmit to the respiratory organs the whole of the blood that has been returned in a carbonated state by the great veins of the system. The very large proportion of red corpuscles contained in the blood, gives additional effect to these provisions. The very high amount of respiration which is natural to Birds, and which cannot be suspended even for a short time without fatal consequences, has a direct relation (as already explained) with their extraordinary muscular activity, as well as with the high bodily temperature which they are fitted to maintain, and which cannot be lowered in any great degree without the suspension of their other functions. Birds are peculiarly susceptible of impurities in the atmosphere; and it has been shown by experiment, that if a Bird, a Mammal, and a Reptile, be placed together in a limited quantity of air, which gradually becomes vitiated by their respiration, the Bird will die first, the Mammal next, and the Reptile last. Or if the Bird be placed alone in a limited quantity of air, and be

left until the atmosphere is so vitiated as to be no longer capable of supporting its life, a Mammal will still live for a time in that atmosphere; and when it is no longer fit to sustain the life of the Mammal, the Reptile may still breathe it without injury for a considerable period. There is strong reason to believe, indeed, that in former epochs of the Earth's history, when the Reptile class was predominant,—supplying the place of Mammals on land, and of Birds in the air,—the atmosphere was so highly charged with carbonic acid, as not to be capable of sustaining the life of the higher air-breathing Vertebrata.

3. *Mechanism of Respiration in Mammalia and in Man.*

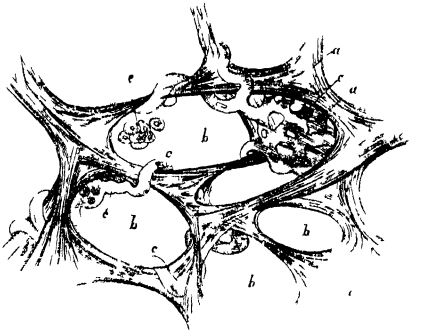
675. It is in the class of Mammalia, that we find the Respiratory apparatus presenting its highest degree of concentration, and the arrangements for its action the most complete. The Lungs are divided into cavities of extreme minuteness, so that the extent of surface which they expose is enormously increased. These cavities, or air-cells, are all connected with the trachea, by means of the bronchial tubes and their minute subdivisions; but, on account of the minuteness of these passages, a considerable force would be required to inflate the air-cells with air, if their distension were to be accomplished by the propulsion of air through the trachea, as we have seen to be the normal mode of inspiration in Reptiles. Moreover, if the air were introduced in this manner, the air-cells would be the *last* portions of the pulmonary structure that would be distended by it, as well as the first to be emptied when the air is forced-out again by external pressure. The mechanism of Respiration in Mammalia, however, is so arranged, that the air is most effectually *drawn into* the lungs, instead of being *forced into* them; and the distension of the air-cells is far more complete than it could be rendered in the latter method, besides being accomplished in a much shorter time.

676. The general principle of the operation is this. The lungs are suspended in a cavity that is completely closed; being bounded above and around by the bony framework of the thorax, the interspaces of which are filled-up by muscles and membranes; and being entirely cut-off from the abdomen below, by the diaphragm. Under ordinary circumstances, the lungs completely fill the cavity; their external surface, covered by the pleura, being everywhere in contact with the pleural lining of the thorax. But the capacity of the thoracic cavity is susceptible of being greatly altered by the movements of the ribs, and by the actions of the diaphragm and abdominal muscles; as will presently be explained in more detail. When it is diminished, the lungs are compressed, and a portion of the air contained in them is expelled through the trachea. On the other hand, when it is increased, the elasticity of the air within the

lungs causes them immediately to dilate, so as to fill the vacuum that would otherwise exist in the thoracic cavity; and a rush of air takes-place down the air-tubes, towards the air-cells, to equalize the density of the air they include (which has been rarefied by the dilatation of the containing cavities) with that of the surrounding atmosphere.

677. The diameter of the ultimate air-cells of the Human lung varies from about the 1-200th to the 1-70th of an inch. Their shape is irregular; and their walls are, for the most part, flattened against each other. Each of the ultimate ramifications of the bronchial tubes communicates with a cluster of these air-cells grouped about it; those which are in immediate proximity with the tube open into it by well-defined circular apertures; and the others communicate with it, by opening into these and into each other. Each air-cell (Fig. 112, *b*, *b*, *b*) is lined by an extension of the

Fig 112.*

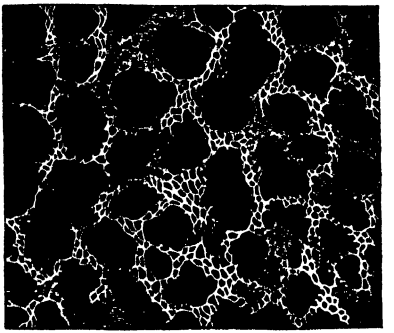


mucous membrane from the bronchial tubes; and this is furnished with a covering of pavement-epithelium (*e*). Between the adjacent air-cells is a network of fibrous tissue (*a*, *a*, *a*), that forms the connecting medium by which they are held-together; this tissue appears to be of the elastic kind. The pulmonary arteries subdivide into branches, whose ultimate ramifications form an extremely minute capillary plexus (Fig. 113); and this is so disposed between the walls of the adjacent air-cells, that each portion of

* Thin section of the Lung of an Infant, showing its minute structure — *a*, *a*, *a*, bands of elastic fibrous tissue, lying between the air-cells *b*, *b*, *b*, *c*, *c*, *c*, capillaries forming a plexus underneath the basement-membrane of the air-cells, *e*, epithelium-cells.

this plexus comes into relation with the air (through the lining membrane of the contiguous air-cells) on *both* sides,—an arrangement which is obviously the most favourable that can be, as regards the aeration of the contained blood. It has been calculated by M. Rochoux, that the number of air-cells grouped around each terminal bronchus is little less than 18,000; and that the total number in the lungs amounts to *six hundred millions*. If this estimate be even a remote approximation to the truth, it is evident that the amount of surface exposed by the walls of these minute cavities, must be very many times greater than that of the whole exterior of the body.

Fig. 113.*



678. The larger bronchial tubes are more or less cartilaginous; but the smaller branches do not possess any such deposit in their walls, though still retaining their circular form. We find in the latter a fibrous structure, which seems to possess the properties of non-striated muscle; and by this the diameter of these tubes appears to be governed. The contractility of the walls of the smaller bronchi may be excited by chemical, electrical, or mechanical stimuli applied to themselves; though it is not so readily caused to manifest itself by stimulating the nerves. By the continued influence of galvanism, bronchial tubes of a line in diameter have been made to contract until their cavity was nearly obliterated: and it has been found by Volkmann that a similar effect may be produced by galvanising the Par Vagum. Supposing the muscular fibres of the bronchial tubes to contract during expiration, the effect of such contraction would be to diminish both the length and the diameter of the tubes, and thus to force-out their contained air. Whether

* Arrangement of the Capillaries of the air-cells of the Human Lung.

such contraction, alternating with relaxation, takes place automatically, as a part of the ordinary rhythmical movements of respiration, has not yet been clearly made-out; but in its tonic form it manifests itself strongly in certain diseased conditions, especially in spasmodic Asthma, which appears essentially to consist in a contracted state of the smaller bronchial passages, occasioning an interruption to the passage of air through them. It is interesting to observe, that the contractility of the muscular walls of these tubes has been experimentally found to be greatly diminished by the application of vegetable narcotics, especially stramonium and belladonna, —substances which are well-known to have a powerful remedial influence in spasmodic Asthma.

679. The tissue of the parenchyma of the Lungs (§ 677) is possessed of a degree of elasticity which prevents these organs from being by any means passive in the respiratory function. This is seen in the collapse which takes-place when the thoracic cavity is laid-open; but as the lungs do not by any means completely empty themselves of air, even when quite free to do so, it is obvious that a partially distended state of these organs is that which is induced by the properties of their own structure, a fuller dilatation or a complete expulsion of the contained air requiring some external force for its production. Now even when the expiratory effort has been most powerful, the lungs are not more emptied of air than they are when left entirely free; whilst every degree of inspiratory effort will have to overcome their elasticity, the resistance caused by which will be proportional to the distension, amounting, for the fullest possible inspiration, to as much as 150lbs. for the male and 123½lbs. for the female.

680. The dilatation of the cavity of the chest, which constitutes Inspiration, is accomplished by two sets of movements;—the elevation of the ribs;—and the depression of the diaphragm. From the peculiar mode in which the ribs are articulated with the spinal column at one extremity, and from the angle which they make with the cartilages that connect them to the sternum at the other, the act of elevation tends to bring the ribs and the cartilages more into a straight line, and to carry the former to a greater distance from the median plane of the body, whilst the sternum is also thrown forwards. Consequently the elevation of the ribs increases the capacity of the thorax, upwards, forwards, and laterally. The movement is chiefly accomplished by the Scaleni muscles, which draw-up the first rib; and by the Intercostals, which draw the other ribs into nearer proximity with each other, so that the total amount of movement in each rib increases as we pass from above downwards,—every one being drawn-up by its connection with the one above it, and being drawn nearer to it by the action of its own intercostals. The elevation of the ribs is further assisted by the Serratus magnus, and by other muscles connected with the spine

and the scapula; and when the respiratory movement is very forcibly performed, the scapula is itself drawn upwards by the muscles that descend to it from the neck, thus producing an increased elevation of the ribs, and an unusual enlargement of the upper part of the thoracic cavity.—When the Expiratory action is to be performed, the descent of the ribs is occasioned by the muscles of the spine and abdomen, which proceed upwards from the lower part of the trunk; and this action is aided by the elasticity of the costal cartilages.—The aid which the elasticity of the parietes of the chest gives to the expiratory movement, and the consequent resistancy which it makes to the inspiratory movement, is a very important element in the estimate of the force put-forth by the muscles. It is stated by Dr. Hutchinson as the results of his experiments, that the introduction of 70 cubic inches of air into a chest of moderate capacity, requires a force of 104lbs.; that when 190 cub. in. are forced-in, the elastic pressure to be overcome is 326lbs.; and that when 200 cub. in. are made to enter, the pressure rises to 452 lbs.;—and this independently of the elastic pressure of the lungs themselves.

681. In the ordinary act of inspiration, however, the Diaphragm performs the most important part. The contraction of this muscle changes its upper surface, from the high arch that it forms when relaxed and pushed-upwards by the viscera below, to a much more level state; though it never approaches very closely to a plane, being somewhat convex even when the fullest inspiration has been taken. When thus drawn down, it presses upon the abdominal viscera, and causes them to project forwards, which they are allowed to do by the relaxation of the abdominal muscles. In tranquil breathing, this action is alone nearly sufficient to produce the requisite enlargement of the thoracic cavity: the position of the ribs being very little altered.—In the expiratory movement, the diaphragm is altogether passive; for, being in a state of relaxation, it is forced upwards by the abdominal viscera, which are pressed inwards by the contraction of the abdominal muscles. These last, therefore, are the main instruments of the expiratory movement; diminishing the cavity of the chest by elevating its floor, at the same time that they draw its bony framework into a narrower compass.

682. In this manner, by the regularly-alternating dilatation and contraction of the thoracic cavity, the air within the lungs is alternately increased and diminished in amount; and thus a regular exchange is secured. This exchange, however, can only affect at any one time a certain proportion of the air in the lungs; thus it is probable, that the quantity remaining in these organs after a *forced* expiration is from 75 to 100 cubic inches, and that the air which remains after an *ordinary* expiration is about 150 cubic inches, whilst the amount usually changed by the respiratory movements

is not above 20 cubic inches. Indeed if it were not for the tendency of gases to mutual diffusion, the air in the remote air-cells would never be renewed.—If any aperture exist by which air could obtain direct access to the pleural cavity, the lungs would not be dilated by its enlargement; for the vacuum would be supplied much more readily by the direct ingress of the air (provided the aperture be large enough), than by the distension of the lung. Thus a large penetrating wound of the thoracic cavity may completely throw out of use the lung of that side; and the same result will follow, when an aperture forms by ulceration in the substance of the lung itself, establishing a free communication between the pleural cavity and one of the bronchial tubes; so that, of the air which rushes-in by the trachea to compensate for the enlargement of the thoracic cavity, a great part goes at once into that cavity, without contributing to the distension of the lungs, and therefore without serving for the aeration of the blood.

683. The number of the respiratory movements (that is, of the acts of inspiration and expiration taken together) may be probably estimated at from 14 to 18 per minute, in a state of ordinary health and of repose of body and mind. Of these the greater part are moderate in amount, involving little movement except in the diaphragm; but a greater exertion, attended with a decided elevation of the ribs, is usually made at every fifth recurrence. The frequency of the respiratory movements, however, is liable to be greatly increased by various causes, such as violent muscular exertion, mental emotion, or quickened circulation; whilst it may be diminished by torpidity of the nervous centres on whose agency the movement depends,—as we see in apoplexy, narcotic poisoning, &c. An acceleration seems very constantly to take place in diseases which unfit a part of the lung for the performance of its function; and the rate bears a proportion to the amount thus thrown out of use. Thus, the usual proportion between the respiratory movements and the pulse being as 1 to 4½ or 5, it may become in Pneumonia as 1 to 3, or even in severe cases as 1 to 2; the increase in the number of respiratory movements being much greater in proportion, than the augmentation of the rate of the pulse. But it must be remembered by the practitioner, that a simply hysterical state may produce, in young females, an extraordinary accceleration of the respiration; the number of movements being sometimes no less than 100 per minute. There will be a great increase, also, in the number of inspirations, when the regular movements are prevented from being fully performed, by any cause that affects their mechanism, even whilst the lungs themselves are quite sound. Thus in inflammation of the pleura or pericardium, or in rheumatic affections of the intercostal muscles, the full action of the ribs is prevented by the pain which the movements produce; and the same is the case in regard to the diaphragm, when the peritoneum or

the abdominal viscera are affected with inflammation. Under such circumstances, there is an involuntary tendency to make-up for the deficiency in the *amount* of the respiratory movements, by an increase in their *number*.

684. The combined actions of the respiratory muscles which have been now explained, belong to the group termed *reflex;* being the result of the operation of a certain part of the Nervous centres, which does not involve the will or even sensation, and which may continue when all the other parts of the nervous centres have been removed. In the Invertebrated Animals, we commonly find a distinct ganglionic centre set-apart for the performance of the respiratory movements; and the division of the nervous centres in Vertebrated animals which is the seat of the same function, may be clearly marked-out, although it is not so isolated from the rest. It is, in fact, that segment of the Medulla Oblongata and upper part of the Spinal Cord, which is connected with the 5th, 7th, and 8th pairs of cephalic nerves, and with the phrenic. The entire brain may be removed from above (by successive slicing), and the whole spinal cord may be destroyed below; and yet the respiratory movements of the diaphragm will still continue,—those of the intercostal and other muscles being of course suspended by the destruction of that portion of the cord from which their nerves arise. But if the spinal cord be divided, between the point at which it receives the 5th and 8th pairs of nerves, and that at which it gives origin to the phrenic, the movements of the diaphragm immediately cease; and this is the reason why death is so instantaneous, in cases of luxation or fracture of the higher cervical vertebræ, causing pressure upon the spinal cord just below its exit from the cranium; whilst if the injury take-place below the origin of the phrenic nerve, life may be prolonged for some time.

685. The Respiratory movements, like other reflex actions (§ 394), depend upon a *stimulus* of some kind, originating at the extremities of the nerves, propagated towards the centre by the afferent trunks, and giving-rise to a motor impulse, which is transmitted along the efferent or motor nerves to the muscles, and which occasions their contraction. Now the importance of the respiratory function to the maintenance of life, which has already been sufficiently pointed-out, necessitates an ample provision for its due performance; and thus we find that the stimulus for the excitement of the movements may be transmitted through several channels. Its chief source, no doubt, is in the lungs; and arises from the presence of venous blood in the capillaries, and of carbonic acid in the air-cells. Under ordinary circumstances,—that is, when the blood is being duly aerated, and the air being properly renewed,—the impression thus made upon the nerves of the lungs is so faint, that we cannot perceive it even when we specially direct our attention to it. But if we suspend the movements for a moment or two, we imme-

diately experience a sensible uneasiness. The Par Vagum is obviously the channel through which this impression is conveyed to the nervous centres; and it is found that if the trunk of this nerve be divided on both sides, the respiratory movements are greatly diminished in frequency. Hence it is undoubtedly one of the principal *excitors* of the respiratory movements.

686. But the sensory nerves of the general surface, and more particularly the sensory portion of the Fifth pair which supplies the face, are most important auxiliaries as *excitor* nerves; the inspiratory movement being peculiarly and forcibly excited by impressions made upon them, especially by the contact of cold air or water with the face. The power of the impression made by the air upon the general surface, and particularly upon the face, in exciting the inspiratory movement, is well seen in the case of the first inspiration of the new-born infant, which appears to be excited solely in this manner. An inspiratory effort is often made, as soon as the face has emerged from the Vagina of the mother; whilst on the other hand, if the face be prevented from coming into contact with cool air, the inspiratory effort may be wanting. When it does not duly take place, it may often be excited by a slap with the flat of the hand upon the nates or abdomen; a fact which shows the special influence of impressions upon the general surface, in rousing the motor impulse in the Medulla Oblongata, and in causing its transmission to the muscles. The deep inspirations which follow a dash of cold water upon the face, or the descent of the cold douche or of the divided streams of the shower-bath upon the body, or the shock of immersion in the cold plunge-bath, all testify to the powerful influence of such impressions in the adult; and the efficacy of other kinds of irritation of the skin, such as beating with holly-twigs, in maintaining the respiratory movements in cases of narcotic poisoning, shows that the required impressions are not restricted to the contact of cold air or water. It seems probable, from various facts, that the presence of venous blood in the arterial capillaries of the system, and the consequent stagnation in the current through them (§ 597), may exert an influence through the Sympathetic nerves, which may be transmitted, by the copious inosculations of that system with the Par Vagum, to the Medulla Oblongata, and which may there serve as a valuable auxiliary in exciting the respiratory movements.

687. Of the mode in which the impressions thus transmitted to the Medulla Oblongata, act in exciting the motor impulses which issue from it, nothing is known; but these impulses, directed along the phrenic, intercostal, and other nerves, produce the requisite movements. When the stimulus is unusually strong, various nerves and muscles are put in action, which do not co-operate in the ordinary movements of inspiration; and it may sometimes be observed that movements are thus excited in parts which will not

act in obedience to the Will, being to all appearance completely paralysed. This fact shows how completely the class of actions in question is independent of the influence of the mind; but we must not lose sight of the control which the mind, especially in the higher classes of animals, possesses over them. Various actions of the respiratory muscles, particularly those of weeping and laughing, are the most direct means of expressing the passions and emotions of the mind; and are involuntarily excited by these. And, again, the respiratory actions are placed to a certain degree under the control of the Will; in order that they may be subservient to the production of vocal sounds, and to the actions of speech, singing, &c. The will cannot long *suspend* the respiratory movements; for the stimulus to their involuntary performance soon becomes too powerful to be any longer resisted. And it is well that it should be so; for if the performance of this most important function were left to our own choice, a few moments of forgetfulness would be productive of fatal results. But it is to the power which the will possesses, of directing and controlling the respiratory movements, that we owe the faculty of producing articulate sounds, and thus of holding the most direct and intimate converse with each other.

688. It is essential for the due performance of the respiratory movements, that the portion of the nervous centres on which they depend should be in a state of activity. This is the case, under ordinary circumstances, throughout life. The state of perfect quiescence to which the Brain is liable, never affects the Medulla Oblongata; and the respiratory movements are consequently kept up with as much regularity and energy (in proportion to the requirements of the system), during our sleeping, as during our waking hours. But if any cause induce torpidity of the medulla oblongata, the respiratory movements are then retarded, or even suspended altogether; and all the consequences of the cessation of the aeration of the blood speedily develope themselves (§ 706). This is seen in apoplexy; when the pressure or other cause of suspended activity, which at first affected the brain alone, gradually propagates its influence downwards. The same is the case in narcotic poisoning; in which also the brain is the first to be affected, and may suffer alone; but if the noxious influence be propagated to the medulla oblongata, it manifests itself in the retardation of the respiratory movements, and, when sufficiently powerful, in their complete suspension. Under such circumstances, it is requisite to resort to all possible means of keeping-up the respiratory movements; and when these fail, artificial respiration may be successfully employed. For if, by such means, the circulation can be prevented from failing for a sufficient length of time, the ordinary processes of nutrition go-on, the poisonous matter is gradually decomposed, or is eliminated by the secreting organs; and the nervous centres resume their usual

functions. A torpid condition of the medulla oblongata, inducing a retardation of the respiratory movements, seems to be one of the morbid conditions attendant upon typhoid fever; and probably depends in the first instance upon a disordered state of the blood, which does not exert its usual vivifying influence. In such cases, the proportion of the respiratory movements to the pulse sinks as low as 1 to 6, or even as 1 to 8; and thus the due aeration of the blood is not performed, and its stimulating properties are still further diminished.

4. *Chemical Phenomena of Respiration.*

689. Having now fully considered the means by which the Atmosphere and the Blood are brought into relation in the lungs, we have to examine into the results of their mutual action. It will be remembered that the Atmosphere contains about 21 per cent. of Oxygen to 79 of Nitrogen, by *measure;* or 23 parts of Oxygen to 77 of Nitrogen, by *weight*. The changes which it undergoes in Respiration may be considered under four heads:—1. The disappearance of Oxygen which is absorbed. 2. The presence of Carbonic Acid which has been exhaled. 3. The absorption of Nitrogen. 4. The exhalation of Nitrogen. Of these, the first two are by far the most important.—It was formerly supposed that the Oxygen which disappears, is the precise equivalent of the Carbonic Acid which is set-free (the latter gas containing its own bulk of the former); and that the union of the absorbed oxygen with the carbon to be eliminated, takes-place in the lungs. It is now known, however, that the carbonic acid is given-out ready formed, its production having taken-place at the expense of oxygen previously contained in the blood; and that a much larger proportion of oxygen is usually absorbed, than is contained in the carbonic acid exhaled, the difference sometimes exceeding the third part of the carbonic acid formed, whilst it is sometimes so small that it may be disregarded. This diversity seems to depend, partly upon the constitution of the species experimented-on, and partly upon the degree of development of the individual, but in great part upon the nature of the food; it having been established by the experiments of MM. Regnault and Reiset, that the quantity of oxygen absorbed into the system is much greater on an animal diet, than on a farinaceous. It is certain that, of this absorbed oxygen, a part must enter into combination with the sulphur and phosphorus of the original components of the body, converting these into sulphuric and phosphoric acids; and the remainder must enter into other chemical combinations, a large share uniting with the hydrogen of the fatty matter, to form part of the water which is exhaled from the lungs.

690. This interchange would seem to depend upon the tendency which all gases have to mutual admixture, when they are sepa-

rated by a porous septum. According to the law discovered by Prof. Graham, the relative volumes of the gases which will thus replace each other, are inversely as the square-roots of their specific gravities; thus, the specific gravity of oxygen being to that of hydrogen as 16 to 1, the replacing volume of oxygen is to that of hydrogen as 1 to 4. The same holds good, when one of the gases is absorbed by a liquid; provided the replacing gas be also capable of being absorbed to the same extent. On this principle, the replacing volume of oxygen is to that of carbonic acid as 1174 to 1000; but as the actual amounts interchanged do not constantly follow this ratio, it is obvious that they are liable to be modified by other conditions, these being chiefly (it seems probable) the relative quantities of the two gases already present in the blood, and the relative facility with which they are absorbed into it or extricated from it.

691. It is difficult to form an exact estimate of the actual quantity of Carbon thrown-off from the lungs in the form of Carbonic Acid during any lengthened period; since the amount disengaged during experiments carried-on for a limited time, cannot, for many reasons, be taken as affording a fair average. Thus the quantity will vary with the external temperature, with the state of previous rest or activity, with the length of time that has elapsed since a meal, and particularly with the general development of the body. The amount of carbonic acid exhaled is greatly increased by external cold, as is shown in the results of such experiments as the following:—Small Birds and Mammals having been enclosed in a limited quantity of air, for the space of an hour, at ordinary temperatures, the quantity of carbonic acid they produced was noted. The experiment was then repeated at a temperature nearly approaching that of the body; and was performed a third time at a temperature of about 32°. The following are the comparative amounts.

	Temp. 59°–68°. Grammes.	Temp. 86°–106°. Grammes.	Temp. about 32°. Grammes.
A Canary	0·250	0·129	0·325
A Turtle-dove	0·684	0·366	0·974
Two Mice	0·498	0·268	0·531
A Guinea-pig	2·080	1·453	3·006

Thus it would appear that the quantity of carbonic acid exhaled between 86° and 106° is not much more than *half* of that which is exhaled between 59° and 68°; and is only about *two-fifths* of that which is given-off at 32°.

692. The quantity of Carbonic Acid exhaled during exercise and for a certain time after it, and also after a full meal, is considerably increased; whilst on the other hand it is greatly diminished during sleep. Thus a person who was excreting 145 grains of carbon per

hour whilst fasting and at rest, excreted 165 after dinner, and 190 after breakfast and a walk; whilst he only excreted 100 during sleep. The variation with the general development of the body, and also with the sex and age, is considerable. Thus the exhalation is almost always greater in males, than in females of the same age, at every period of life except childhood.—In *males*, the quantity increases regularly from eight to thirty years of age, remaining nearly stationary until forty: thus it averages 77·5 grains of carbon per hour at eight years; 135 grains at fifteen; 176·7 grains at twenty; and 189 grains from thirty to forty. Between forty and fifty there is a well-marked diminution, the average being then 156 grains; and the diminution continues up to extreme old age, when the amount exhaled scarcely exceeds that which is extricated at ten years of age; thus, between sixty and eighty, it was 142·5 grains; and in a man of a hundred and two, it was only 91·5 grains. These average results, however, are widely departed-from in individual cases; an extraordinary development of the muscular system being always accompanied by a high rate of extrication of carbon, and *vice versâ*. Thus a man of remarkable muscular vigour, whose age was twenty-six years, exhaled 217 grains of carbon in an hour; a robust man of sixty exhaled 209·4 grains; and an old man of ninety-two, who in his younger days had possessed uncommon muscular powers, and who preserved a remarkable degree of energy, still gave-forth at the rate of 151 grains per hour. On the other hand, a man of slight muscular development, at the age of forty-five, only exhaled 132 grains; and another at the age of seventy-six, only 92·4 grains.

693. In *females*, nearly the same proportional increase goes-on, up to the time of puberty; when the quantity abruptly ceases to increase, and remains stationary so long as menstruation continues regular. The average quantity of carbonic acid exhaled by girls nearly approaching puberty, is about 100 grains per hour; and it remains at this standard until nearly the close of menstrual life. At the period of the cessation of the catamenia, it undergoes a perceptible increase; the average between forty and fifty years of age being about 130 grains per hour, and the quantity exhaled in a woman of great muscular development, and of forty-four years of age, rising to 152·4 grains in an hour. After the age of fifty, or thereabouts, the quantity decreases, as in men. It is remarkable that during pregnancy there is the same increase in the exhalation of carbon, as there is after the final cessation of the catamenia; and the same takes-place, if the menstrual discharge be temporarily suspended through any other cause.

694. It is obviously difficult, then, to obtain exact estimates, from any experiments conducted for a short time only, of the total amount of Carbon thrown-off during a lengthened period; since the condition of the same individual varies so much at different times, and

the variation amongst different individuals is so great. Moreover, of the total amount of carbon excreted in a gaseous form, a certain part is undoubtedly set-free from the skin; but the proportion of this does not seem to be considerable. As a means of measuring the whole quantity of carbonic acid set-free, without causing the respiratory movements to be performed in any unnatural manner, Prof. Scharling constructed an air-tight chamber, of dimensions sufficient to allow an individual to remain in it for some time without inconvenience, and so arranged that he could eat and drink, read or sleep, within it. This was connected with an apparatus by which the air was continually renewed; and the air drawn-off was carefully analysed, in order to determine the quantity of carbonic acid contained in it. The average per hour in different states having been ascertained, it was calculated that, allowing seven hours for sleep in adults, and nine hours for children, the *total* amount of carbon consumed in the twenty-four hours would be as follows:—

No.	Weighing.	Grains.	Oz. Troy.
1. A male, aged thirty-five,	131 lbs.	3387	or 7·0
2. A male, aged sixteen,	115½ lbs.	3453	or 7·2
3. A soldier, aged twenty-eight,	164 lbs.	3699	or 7·7
4. A girl, aged nineteen,	111 lbs.	2540	or 5·3
5. A boy, aged nearly ten,	44 lbs.	2054	or 4·3
6. A girl, aged ten,	46 lbs.	1930	or 4·0

695. This estimate is unquestionably too low, as it does not take sufficient account of the great increase which is produced by exercise.—Another method has been adopted by Prof. Liebig, who endeavoured to ascertain the total amount of carbon excreted from the body in the form of carbonic acid, by comparing the amount of carbon taken-in as food, with that contained in the fæces and urine; the difference being set-down to the account of respiration. His estimate amounts to the very large sum of 13·9 oz. of solid carbon per day, which he considers to be thus set-free by the lungs and skin; but this is almost certainly above the truth. The observations were made upon a body of soldiers who were subjected to severe daily exertion; and they were far from being exactly conducted, many of the items being set-down by guess only, whilst of others no account whatever was taken. We may perhaps consider 10 or 11 oz. as more nearly representing the amount of carbon consumed by adult men exposed to severe exertion; whilst from Prof. Scharling's experiments it may be inferred, that from 7 to 8 oz. of carbon are thrown-off during the twenty-four hours, by the lungs and skin of adult men not using much active exertion; to which another ounce or two may be added, as the increased quantity excreted during moderate exercise.—In a subsequent series of experiments, Prof. Scharling ascertained the proportion of carbonic

acid given-off from the general surface of the human body, to be from about 1-30th to 1-50th of the whole amount; so that, adopting 1-40th as the average, out of eight ounces of carbon exhaled, only one-fifth of an ounce is set-free in the form of carbonic acid from the Skin.

696. If we assume 8 oz. or 3840 grains of solid Carbon, as the total amount excreted from the lungs of a male adult using moderate exertion, in the course of twenty-four hours, we find that the volume of carbonic acid thus generated must be about 29,500 cubic inches, or 17 cubic feet. Now it seems probable that the whole quantity of air which passes through the chest during that time under similar circumstances, is about 400 cubic feet; so that the proportion of carbonic acid contained in the expired air averages something more than 4 per cent. It is certain, however, that this proportion may rise much higher; particularly when the respiratory movements are slowly and laboriously performed. Now in order that the blood should be properly aerated, it is requisite that the air should contain no previous impregnation of carbonic acid; since the diffusion of even a moderate per-centage of that gas through the inspired air seriously impedes the exhalation of more. Thus it was found by Messrs. Allen and Pepys, that, when 300 cubic inches of air were respired for three minutes, only 28¼ inches of carbonic acid (or somewhat more than 9 per cent.) were present in it; though the rate of its production in a parallel experiment, in which fresh air was taken-in at each inspiration, was 32 cubic inches per minute, or 96 cubic inches in three minutes. It appears from the experiments of Dr. Snow, that the presence of carbonic acid in the atmosphere acts more deleteriously on the system, in proportion as the normal quantity of oxygen has been reduced; and hence, that the *substitution* of carbonic acid for oxygen by the respiratory process, vitiates the air far more effectually than the introduction of a *surplus* of carbonic acid, the normal quantity of oxygen being still present. He concludes from his experiments upon the lower animals, that 5 or 6 per cent. of carbonic acid cannot exist in an atmosphere respired by Man without danger to life; and that less than half this amount would soon be fatal, when it is formed at the expense of the oxygen of the air. A still smaller proportion is capable of producing very injurious results. Thus the discomforts occasioned by the presence of a crowded audience in a church, lecture-room, or theatre, which is not provided with sufficient ventilation, are due in great part to the continued respiration of air which becomes loaded in the course of an hour or two with carbonic acid gas, to the amount of from one-half to two per cent., —as has been ascertained both by direct experiment, and by calculation. And there can be no reasonable doubt, that the habitual respiration of such air, in the narrow and noisome dwellings of the poor, or in crowded factories and workshops, has a

tendency to produce, both directly and indirectly, much loss of physical and mental vigour, and also to blunt the acuteness of the moral feelings. Its influence is specially noticed in increasing the predisposition to epidemic diseases, and in augmenting the fatality of their attacks.

697. The effects of a simple deficiency of Oxygen in the respired air, are experienced by those who breathe a rarefied atmosphere, such as that which exists on the summits of high mountains. All persons who have made such ascents, have experienced the insufficiency of rarefied air to sustain the degree of respiration required for active exertion. So long as the body remains at rest, no inconvenience is perceived; but as soon as the muscular system is put into action, the insufficiency of the supply of oxygen is manifested by the feeling of distress and languor, which becomes so severe, that the individual, if unused to such ascents, is obliged to stop and take breath at every few steps. The necessity for doing so will be easily understood, when it is remembered that when the *pressure* of the atmosphere is reduced to *half* its usual amount, the *bulk* of a given weight of air will be *twice* as great as at the surface of the earth, or the *same* measure will weigh only *half* as much. Consequently, when the chest is completely filled with air, the real quantity of oxygen included in it, is only half of that which is drawn-in by a corresponding inspiration at the earth's surface.

698. With regard to the absorption and exhalation of Nitrogen, it seems probable that both these processes are constantly going-on; but that their relative activity varies under different conditions. Thus it has been ascertained by MM. Regnault and Reiset, that although warm-blooded animals, when subjected to their ordinary regimen, usually increase the amount of nitrogen in the atmosphere, yet when food is withheld, or the animals are fed upon a diet to which they are unaccustomed, an absorption of nitrogen takes place; this being particularly remarkable in the hybernating Mammalia, in which the gain in weight by the absorption of oxygen and nitrogen even exceeds the loss occasioned by the exhalation of carbon.

699. Having thus considered the changes produced by the Respiratory function, in the *air* submitted to it, we have next to inquire into converse series of changes effected by it in the *blood*. The nature of these cannot be well stated with precision, as they have not yet been fully determined. It was formerly supposed that the venous blood arrives at the lungs charged with carbon, and that this carbon is united with the oxygen of the air in the lungs themselves. Numerous facts, however, go to prove that the blood comes to the lungs charged with carbonic acid; and that it gives-out this ready formed, and receives oxygen in its stead. Thus it has been already shown that there is a positive disappearance of oxygen, more of that element being withdrawn from the atmosphere than is

restored to it in the condition of carbonic acid; so that we know that the surplus must be received into the blood. Further, cold-blooded animals may be made to breathe nitrogen or hydrogen for a sufficient length of time to cause a large quantity of carbonic acid to be disengaged; and this must have been brought to the lungs ready formed, since no oxygen was present there to generate it. Lastly, it can be shown by experiment that oxygen, carbonic acid, and nitrogen exist in a free state in blood, arterial as well as venous; but that the proportion of oxygen is greater in arterial than in venous blood, whilst that of carbonic acid is less. The following table expresses the percentage of each kind of gas in the two sorts of blood respectively, as deduced from the experiments of Magnus.

	Arterial Blood.	Venous Blood.
Carbonic acid . .	62·3	71·6
Oxygen . . .	23·2	15·3
Nitrogen . . .	14·5	13·1

Thus it appears that the quantity of nitrogen is very nearly the same in both, as would be anticipated from what has been already stated in regard to its non-participation in the respiratory process; whilst about one-third of the free oxygen of arterial blood disappears during its circulation in the systemic capillaries, to be replaced by an equivalent amount of carbonic acid; and a converse change takes-place in the pulmonary capillaries, this additional portion of free carbonic acid being set-free, and replaced by oxygen.

700. Thus it is evident, that a part of the change effected in the Blood consists in an alteration in the proportion of the gases which always exist in it, either entirely free, or in a state of such loose combination that they can be removed by the air-pump. But it is pretty certain that a portion of the effect consists in the oxidation of the protein of the fibrinous constituent; since the fibrin of arterial blood possesses properties that distinguish it from that of venous (§ 176). It has usually been supposed that the hematin of the red corpuscles undergoes a change under the influence of oxygen in the lungs, and a converse change in the systemic capillaries, where it is subjected to the influence of carbonic acid; this change being indicated by the alteration in the colour of the red corpuscles. The alteration in question, however, seems due rather to a physical than to a chemical change (§ 222); and we have no direct evidence, though much that is indirect, of the special influence of the aeration of the blood upon the contents of the red corpuscles. It appears tolerably certain that a part of the oxygen imbibed in the lungs, is appropriated to the oxidation of the matters set-free by the decomposition of the solid tissues; whilst another part enters into combination with fatty, saccharine, farinaceous, and other matters, existing in the blood itself, and destined to be carried-off in the

form of carbonic acid and water, without ever entering into the composition of the solid fabric. The relative amounts of carbonic acid formed in these two modes, vary in different animals, and in different states of the same individual; for a man in a warm atmosphere, taking a moderate amount of exercise, may thus set-free, by the waste of his muscular and other tissues, a sufficient quantity of carbon for the maintenance of his animal heat by its union with oxygen; but this is far from being sufficient, when a larger amount of heat must be evolved to sustain the temperature of the body in a colder climate.

701. The blood parts in the lungs with a very large amount of moisture; for the inspired air is always saturated with fluid, as soon as it reaches the air-cells; and, as it is heated at the same time to about 98°, it thus receives a considerable addition, even if it were previously charged with as much as it could contain at a lower temperature. The total quantity of fluid thus disengaged will vary, therefore, with the amount previously contained in the atmosphere, being greater as this was less, and *vice versâ;* but the quantity that usually passes-off seems to be from 16 to 20 ounces in the twenty-four hours. It cannot be doubted that a great part of this water is a simple exhalation of that which has been absorbed; but, on the other hand, it has been proved by a comparison of the hydrogen of the food with that given-off by other excretions, that a portion of it must be actually formed in the system, by the union of a portion of the oxygen absorbed in the lungs with the hydrogen of the combustible matters of the blood. In the various forms of saccharine and farinaceous aliments, the proportions of hydrogen and oxygen are such as would of themselves form water, when the carbon is withdrawn; but in oily and fatty matters, the proportion of oxygen is far too small thus to neutralize the hydrogen; and thus, by their oxidation in the blood, as by their combustion elsewhere, water is actually generated by the union of atmospheric oxygen with their hydrogen, at the same time that carbonic acid is produced by its union with their carbon.

702. Along with the water thus extricated from the lungs, a certain amount of organic matter is set-free. If the fluid be collected in a closed vessel, and be exposed to warmth, a very evident putrid odour is exhaled from it; and if the expired air be made to pass through sulphuric acid, that liquid is coloured red. Every one knows that the breath itself possesses, occasionally in some persons, and constantly in others, a fœtid taint; when this does not proceed from carious teeth, ulceration in the air-passages or lungs, or other similar causes, it must result from the excretion of the putrescent matter, in combination with watery vapour, from the pulmonary surface. That this is the true account of it, seems evident from the analogous phenomenon of the exhalation of turpentine, camphor, alcohol, and other odorous substances, which have

been introduced into the venous system either by natural absorption or by direct injection; and also from the suddenness with which the odour manifests itself, when the digestive apparatus is slightly disordered. The effect of *overcrowding* is specially to increase the amount of this miasmatic exhalation, which is given off from the skin as well as from the lungs; and air thus charged with decomposing matter seems to be the most fitting *pabulum* for the development of Zymotic poisons.

5. *Effects of Insufficiency, or Suspension, of the Aerating Process.*

703. The change which the Blood undergoes, by being brought into relation with atmospheric air in the respiratory organs, is so important to life, that the entire suspension of it inevitably produces a fatal termination at no remote period; and if it be insufficiently performed, various disorders in the system are nearly sure to manifest themselves. The state which is induced by the entire suspension of the aerating process, is termed Asphyxia; a word which literally means the absence of pulse, and which would be applicable therefore to the stoppage of the circulation from any cause, though it is usually employed to designate the particular condition resulting from suspended respiration. Asphyxia may be produced in aquatic animals, as well as in those which breathe air, by cutting them off from the influence of the atmosphere; for if a Fish be placed in water from which the air has been expelled by boiling, it is precisely in the condition of an air-breathing animal placed in a vacuum, since it has no power of obtaining oxygen by decomposing the water it inhabits, and is entirely dependent for the aeration of its blood upon the air that is absorbed by the liquid. Again, if a fish be placed in water impregnated with carbonic acid, its death is nearly as instantaneous as that of an air-breathing animal immersed in an atmosphere of that gas.

704. Asphyxia may result from a great variety of causes. Thus there may be a mechanical obstruction to the entrance of air through the trachea; as in hanging, strangulation, or drowning; or as in occlusion of the aperture of the glottis by œdema of its lips, or by the presence of a foreign body in the larynx. Or, again, the passage may be perfectly free, and yet no air may enter, in consequence of some obstacle to the performance of the respiratory movements. This obstacle may be mechanical; as when a quantity of earth has fallen round the body, in such a manner as to completely prevent the distension of the chest and abdomen. Or it may result (and this is a most frequent occurrence) from torpidity or complete inactivity of the ganglionic centre which is concerned in the respiratory actions, or from interruption to the transmission of its influence along the nervous trunks. Further, when there is no

obstacle to the free ingress or egress of air, Asphyxia may be produced by the want of oxygen in the atmosphere that is respired, or by the presence of carbonic acid in too large an amount. And the presence of other gases which exert a directly poisonous influence on the blood,—such as sulphuretted hydrogen,—produces a state which may be included under the same general description.

705. Now when, from any of these causes, the free exchange of carbonic acid for oxygen in the blood passing through the lungs is checked, the first effect of the interruption appears to be the stagnation of that blood in the pulmonary capillaries. This stagnation is evidently due, not to any deficiency of power in the heart, for that organ is not yet affected; but to the insufficiency of the heart's power, acting alone, to drive the blood through the pulmonary capillaries, the force which should be generated by chemical changes in them (§ 598) being deficient. The stagnation is not, however, complete at first; since the quantity of oxygen contained in the lungs is sufficient to produce an imperfect arterialization of the blood; and the blood thus partially changed is transmitted to the left side of the heart, and is thence propelled to the system. Owing to its half-venous condition, it cannot exert its usual stimulating influence on the tissues, especially the muscular and nervous; and their powers are consequently weakened. For the same reason, it does not receive its usual auxiliary force in the systemic capillaries (§ 599); since the changes which it ought to undergo in them, can only be partially performed.

706. As the air included in the lungs loses more and more of its oxygen, and becomes more and more charged with carbonic acid, the aeration of the blood in the pulmonary capillaries becomes more and more imperfect; the quantity of blood which is allowed to return to the heart is gradually diminished, and its condition becomes more and more venous; and at last the pulmonary circulation is altogether suspended. From the relation which the respiratory circulation bears to the systemic, in all the higher classes of animals save Reptiles, it follows that the systemic circulation must in like manner be brought to a stand. The venous blood accumulates in the pulmonary artery, in consequence of the obstruction of its capillaries; it distends the right cavities of the heart; and the accumulation extends to the venous system of the body in general, especially affecting those organs which naturally receive a large quantity of venous blood, such as the liver and spleen. The arterial system, on the other hand, is emptied in a corresponding degree; nearly all its blood having passed through the systemic capillaries; and no fresh supplies being received from the heart. From this deficiency, and from the venous character of the blood which the systemic arteries *do* contain, it results that the nervous and muscular systems lose their power; insensibility comes-on, at first accompanied with irregular convulsive movements; but in a short time there is ...e

total cessation of all movement, except that of the heart; and the pulsations of that organ become feebler and feebler, until they cease altogether. The immediate cause of the cessation of the heart's action appears to be different on the two sides. Both are equally affected by the want of arterial blood in the capillaries of their own substance; but the right side suffers from over-distension, which produces a sort of paralysis of its muscular tissue; whilst the left side retains its contractility, but is not excited to contraction for want of the stimulus of arterial blood in its cavities.

707. In those warm-blooded animals, which are not endowed with any special provision for enabling them to sustain life during the prolonged suspension of the respiratory process, insensibility and loss of voluntary power almost invariably supervene within a minute and a half after the admission of air to the lungs has been entirely prevented; though the respiratory efforts and convulsive actions, which are dependent upon the medulla oblongata and spinal cord, may continue for a minute or two longer. The circulation generally comes to a complete stand within ten minutes at farthest. —The chief exceptions are in the case of diving animals, which are provided with large arterial and venous reservoirs, that serve to maintain the circulation during a prolonged suspension of the respiratory process; for the arterial plexuses being ordinarily filled, they afford a supply of aerated blood to the systemic capillaries when other blood is wanting; and the reservoirs connected with the venous system, which were previously empty, receive this blood, and prevent it from exercising undue pressure on the heart. To such an extent is this provision carried in some animals, that the Whale has been known to remain under water for an hour. Another exception exists in the case of hybernating Mammals, which are reduced for a time to the condition of cold-blooded animals, and which can, like the latter, sustain a prolonged suspension of the aerating process. And there is reason to believe that, in the state of Syncope or fainting,—in which the circulation is already reduced to a very low amount, in consequence of a partial failure in the heart's power, all the functions of the body being nearly suspended, and the demand for aeration being consequently very small, —the respiration may be suspended for a long period, even in the Human subject, without fatal results. Thus more than one case has been credibly recorded, in which recovery has taken-place after complete submersion for more than three quarters of an hour; and it is probable that in these instances, a state of Syncope came-on at the moment of immersion, through the influence of mental emotion, or of concussion of the brain.

708. In the restoration of an animal from the state of Asphyxia, it is above all things of importance to renew the air in the lungs; for in this way the blood in the pulmonary capillaries will be aerated, the capillary circulation will be re-established, the right

side of the heart will be relieved of its excessive load of venous blood, and the left side will receive the stimulus of a fresh supply of arterial blood; so that, if its movements have not ceased altogether, it may be speedily restored to due activity. At the same time the temperature of the body should be kept-up by artificial warmth, and the circulation in the skin should be excited by friction. Where no other means are at hand for introducing pure air into the lungs (of which means the application of galvanism along the course of the phrenic nerve, so as to produce contraction of the diaphragm, will probably be the most effectual), the object may be attained by forcibly compressing the trunk on all sides, so as to empty the lungs as much as possible, and then allowing the chest to dilate again by the elasticity of its walls. In this manner a large proportion of the carbonic acid may be expelled, and a considerable proportion of fresh air introduced, in the course of a few minutes. If air be blown into the lungs by bellows, great care must be taken to prevent the employment of too much force, which is likely to produce rupture of the air-cells.

709. Now when, from the more prolonged action of various causes that impede the due performance of the respiratory function, the aeration of the blood in the lungs is insufficient for health, though not such as to produce a complete stagnation of its movement, a variety of results may follow; of which some, or others, will manifest themselves, according to the condition of the general system, and the peculiarities of the individual. Thus deficient respiration seems to favour the retention of fatty matter in the system; and this not merely in the condition of Adipose tissue, which (unless it accumulate to excess) may be regarded as a healthy product; but also in the place of the normal components of other tissues, as the muscular and glandular, giving rise to the condition which is termed 'fatty degeneration.'—Again, the due elaboration of the plasma of the blood is undoubtedly prevented by an habitually-deficient respiration; and various diseases which result from the imperfect performance of this elaboration, consequently manifest themselves. The *Scrofulous* diathesis is thus frequently connected with an unusually small capacity of the chest.—Further, an habitual deficiency of respiration may impede, though it does not check, the circulation in the lungs; and thus a tendency arises, in various pulmonary diseases, to an overloading of the pulmonary arteries, to a dilatation of the right cavities of the heart, and to a congestion of the venous system in general, as marked by lividity of the surface, by venous pulsation, &c. This state may result, not merely from obstruction in the lungs themselves, but from deficiency of the respiratory movements, consequent upon torpidity of the medulla oblongata (as in apoplexy and narcotic poisoning), or upon partial interruption of the nervous circle requisite for all reflex movements. Thus when the Par Vagum is divided, the number of

respiratory movements is greatly diminished, and a partial stagnation of the blood in the lungs is the result. The same happens in certain forms of typhoid fever, in which the respiratory movements are preternaturally slow, in consequence of torpidity of the medulla oblongata. Now in this state, an effusion of the watery part of the blood into the air-cells of the lungs (as in other cases of obstructed circulation) is very liable to occur; and when the lungs are thus loaded with fluid, the respiratory process is still more impeded, and the disorder has thus a tendency to increase itself.

CHAPTER IX.

OF SECRETION.

1. *Of the Secreting process in general; and of the Instruments by which it is effected.*

710. We have seen that in the process of Nutrition, the circulating current not only *deposits* the materials which are required for the renovation of the solid tissues; but also *takes back* the substances which are produced by the decay of these, and which are destined to be thrown-off from the body. We have also seen that it supplies the materials of certain fluids, which are separated from it to effect various purposes in the economy; such as the Salivary and Gastric fluids, which have for their office to assist in the reduction of the food. Now the process by which the fluids of the latter kind are separated from the Blood, is precisely the same in character as that by which the products of decay are eliminated from it; and the structure of the organs concerned in the two is essentially the same. Hence both processes are commonly included under the general term *Secretion*, which simply denotes *separation*. Considered in its most general point of view, this designation may be applied to *every* act by which substances of any kind are *separated* from the blood. Thus the function of the cells which are concerned in the elaboration of the organizable *plasma*, may be termed one of Secretion, because they draw from the blood a supply of Albumen, upon which their converting action is exercised: but as the product of their operation is returned to the blood again, and is employed for higher purposes in the economy, the process is usually termed Assimilation. In the same manner, the elaborating action of the Lymphatic Glands, with the Spleen, Thymus Gland, &c., is not usually termed Secretion; since, although it is exercised upon

matter drawn from the blood, the product appears to be delivered back into the circulating current, through the medium of the Lymphatic System (CHAP. V.). With much more justice, however, the process of Respiration may be regarded as one of Secretion; for it consists, as we have seen, in the constant elimination of a substance from the blood, which cannot be retained in it without the most injurious consequences.

711. There is an important difference in the characters of the principal products of the Secreting process, which is connected with the purposes that are to be answered by their separation. Some of these products are *altogether different* from the ordinary constituents of the animal fabric, and from the materials which the blood supplies for the nutrition of these. So different are they, that their presence in the circulating current has an injurious effect; and the great object of their separation is the maintenance of the purity of the blood. These poisons, for such they may be considered, are generated in the system by the decay and decomposition to which its several parts are liable; and they are just as noxious to it, as if they were absorbed from without. We have seen that the retention of Carbonic acid in the blood for even a few minutes is fatal, both by putting a stop to the circulation, and by acting unfavourably upon the substance of some of the most important organs in the body. The same fatal result attends the retention of Urea and of Biliary matter, which are among the other products of the decomposition of the tissues; but although as certain, it is not so speedy, because the general circulation is not affected by the loss of secreting power on the part of the Kidneys and the Liver, and because the accumulation of the noxious matter is slower.—On the other hand, the ingredients that are met-with in those secreted fluids which are destined to answer some purpose in the economy, almost invariably bear a close correspondence with the ordinary materials of the blood. Thus in the Salivary, Gastric, Pancreatic, and Lachrymal fluids, the principal part of the solid matter consists of the saline and of the albuminous constituents of the blood, the latter in a more or less altered condition. In Milk, again, we trace the ordinary constituents of the blood, with very little change. Thus it appears that the separation of *these* fluids is not required so much to maintain the Blood in a state of purity, as to supply what is needed for some subsequent operation in the economy; and hence if the secreting process be interrupted in the case of any one of them, the suspension has usually no further effect than that of disturbing the process to which the fluid is usually subservient. If the secretion of Gastric fluid be checked, for example, under the influence of strong mental emotion, the Digestive operation is prevented from taking-place.

712. The essential character of the true *Secreting* operation seems to consist,—not in the nature of the action itself, for this is

identical with those of Assimilation and Nutrition, being (as we have seen, § 239), a process of cell-growth,—but in the position in which the cells are developed, and the mode in which the products of their action are afterwards disposed-of. Thus the epithelial cells at the extremities of the intestinal Villi (§ 238), the cells of which the Adipose tissue is made-up (§ 257), and the cells of which the greater part of the substance of the Liver is formed (§ 242), all have an attraction for fatty matter, and draw it from the neighbouring fluids at the expense of which they are developed, to store it up in their own cavities. But the cells of the first kind, when they have come to maturity, set-free their contents, which are delivered to the absorbent vessels, to be introduced into the circulating current:—those of the second kind seem more permanent in their character, and retain their contents, so as to form part of the ordinary tissues of the body, until they are required to give them up for other purposes, when the matters which they have temporarily separated from the circulating current are restored to it again without change;—and the cells of the third class, when *they* liberate their contents (which they are continually doing), cast them forth into the hepatic ducts, by which they are carried into the intestinal canal, whence a portion of them at least is directly conveyed out of the body.

713. It is, then, in the *position* of the Secreting cells,—which causes the product of their action to be delivered upon a *free surface*, communicating, more or less directly, with an external outlet, —that their distinctive character consists. All the proper *Secretions* are thus either poured-out upon the exterior of the body, or into cavities provided with orifices that lead to it. Thus we shall see that a considerable quantity of solid matter, and a very large quantity of fluid, of which it is desirable that the system should be freed, are carried-off from the Cutaneous surface. Another most important secretion, containing a large quantity of solid matter, and serving also to regulate the quantity of fluid in the body,—namely, the Urinary,—is set-free by a channel expressly adapted to convey it directly out of the body. The same may be said of the Mammary secretion, which is separated from the blood, not to preserve *its* purity, nor to answer any purpose in the economy of the individual, but to afford nutriment to another being. And of the matters secreted by the very numerous glandulæ situated in the walls of the Intestinal canal, a great part are obviously poured into it for no other purpose, than that they may be carried out of the body by the readiest channel.

714. The cells covering the simple membranes that form the free surfaces of the body, whether external or internal, are all entitled to be regarded as *secreting* cells; since they separate various products from the blood, which are not again to be returned to it. But the secreting action of some of these appears to have for its

chief object the *protection* of the surface; thus the Epidermic cells secrete a horny matter, by which density and firmness are imparted to the cuticle; whilst by the epithelial cells of the Mucous membrane of the alimentary canal and of other parts, their protective Mucus seems to be elaborated. But in general we find that special organs termed *Glands* are set-apart for the production of the chief secretions; and we have now to consider the essential structure of these organs, and the mode of their operation. A true Gland may be said to consist of a closely-packed collection of follicles (§ 122), all of which open into a common channel, by which the product of the glandular action is collected and delivered. The follicles contain the secreting cells in their cavities; whilst their exterior is in contact with a network of blood-vessels, from which the cells draw the materials of their growth and development (Fig. 100). In any one of the higher animals, we may trace-out a series of progressive stages of complexity, in the various glands included within their fabric; and in following any one of the glands that attain the highest degree of development (such as the Liver or Kidney), through the ascending scale of the Animal series, we should trace a very similar gradation from the simplest to the most complex form.

715. That there is nothing in the *form* or *disposition* of the components of the glandular structure, which can have any influence upon the character of the secretion it elaborates, is evident from the fact, that the very same product,—*e.g.* the Bile, or the Urine, —is found to issue from nearly every variety of secreting structure, as we trace it through the different groups of the Animal kingdom. The peculiar power by which one organ separates from the blood the elements of the Bile, and another the elements of the Urine, whilst a third merely seems to draw-off a certain amount of its albuminous and saline constituents, is obviously the attribute of the ultimate secreting cells, which are the real agents in the secreting process (§ 241). *Why* one set of cells should secrete Bile, another Urea, and so on, we do not know; but we are equally ignorant of the reason for which one set of cells converts itself into Bone, another into Muscle, and so on. This variety in the endowments of the cells by whose aggregation and conversion the fabric of the higher animals is made-up, is a fact which we cannot explain, and which must be regarded (for the present, at least,) as one of the 'ultimate facts' of Physiological Science.

716. Passing-by the extended membranous surfaces, and the protective cells with which they are covered, we find that the simplest form of a secreting organ is composed of an *inversion* of that surface into a series of follicles, which discharge their contents upon it by separate orifices. Of this we have an example in the *gastric* follicles, even in the higher animals; the apparatus for the secretion of the Gastric fluid never attaining any higher condition than that

of a series of distinct follicles, lodged in the walls of the stomach, and pouring their products into its cavity by separate apertures. In Fig. 114 is represented a portion of the Ventriculus succenturiatus of a Falcon, in which the simplest form of such follicles is seen. A somewhat more complex condition is seen in some of the Gastric follicles of the Human stomach (Fig. 82); the surface of each follicle being further extended by a sort of doubling upon itself, so as to form the commencement of secondary follicles, which open out of the cavity of the primary one.—Now a condition of this kind is common to *all* glands in an early stage of their evolution; and in this stage we meet with them, either by examining them in the lowest animals in which they present themselves, or by looking to an early period of their embryonic development in the highest. Thus, for example, the Liver consists, in certain Polypes and in the lowest Mollusca, of a series of isolated follicles, lodged in the walls of the stomach, and pouring their product into its cavity by separate orifices; these follicles being recognized as constituting a biliary apparatus, by the colour of their secretion. And in the Chick, at an early period of incubation, the condition of the Liver is essentially the same with the preceding; for it consists of a cluster of isolated follicles, not lodged in the walls of the intestine, but surrounding a sort of bud or diverticulum of the intestinal tube, which is the first condition of the hepatic duct, and into which they discharge themselves (Fig. 115). So, again, the Pan-

Fig. 114.*

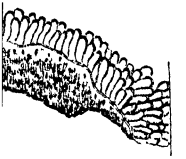


Fig. 115.†

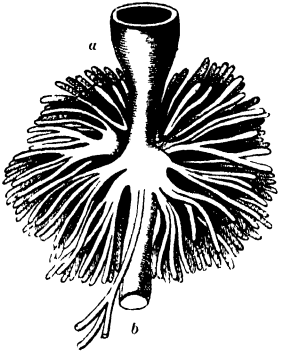


* Glandular follicles in ventriculus succenturiatus of Falcon.

† Origin of the Liver from the intestinal wall, in the embryo of the Fowl, on the fourth day of incubation —*a*, heart; *b*, intestine; *c*, everted portion giving origin to liver; *d*, liver; *e*, portion of yolk-bag.

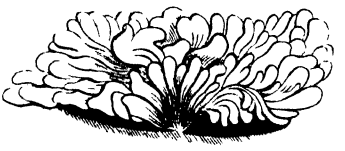
creas first presents itself in the condition of a group of prolonged follicles, or *cæca*, clustered round the commencement of the intestinal tube; and this is its permanent condition in many Fishes (Fig. 116). And the Mammary Gland possesses an equally simple structure in the lowest of all the Mammalia (to which group it is restricted); namely, in the Ornithorhyncus (Fig. 117).

Fig. 116.*



717. The next grade of complexity is seen, where a cluster of the ultimate follicles open into one common duct, which discharges their product by a single outlet; a single gland often containing a number of such clusters, and having, therefore, several excretory ducts. A good example of such a condition, in which the clusters remain isolated from one another, is seen in the Meibomian glands

Fig 117.*



of the eyelid (Fig. 118); each of which consists of a double row of follicles, set upon a long straight duct, that receives the products of their secreting action, and pours them out upon the edge of the eyelid. And of the more complex form, in which a number of such clusters are bound together in one glandular mass, we have an illustration in the accessory glands of the genital apparatus, in several animals, which discharge their secretion into the urethra by numerous outlets (Fig. 119); or in the Mammary

* Rudimentary Pancreas from Cod:—*a*, pyloric extremity of stomach, *b*, intestine.

† Mammary Gland of Ornithorhyncus.

glands of Mammalia in general, the ultimate follicles of which are clustered upon ducts that coalesce to a considerable extent,

Fig. 118.*

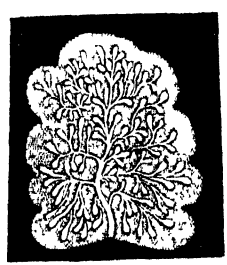


Fig. 119.†



though continuing to form several distinct trunks even to their termination. Such glands may be subdivided, therefore, into *glandulæ* or *lobules*, that remain entirely distinct from each other (Fig. 120).—In the highest form of Gland, however, all the ducts unite; so as to form a single canal, which conveys away the products of the secreting action of the entire mass. This is the condition in which we find the Liver to exist, in most of the higher animals; also the Pancreas, the Parotid Gland, and many others. In some of these cases, we may still separate the gland into numerous distinct lobules, which are clustered upon the excretory duct and its branches, like grapes upon a stalk; in others, however, the branches of the excretory duct do not confine themselves to *ramifying*, but *inosculate* so as to form a network, which passes through the whole substance of the gland, and which connects together its different parts, so as to render the division into lobules less distinct. This

Fig. 120.‡



* Meibomian glands of upper lid of new-born infant.

† Portion of Cowper's gland from Hedgehog; the follicles distended with air.

‡ Lobule of Lachrymal Gland; from fœtal sheep

seems to be the case in regard to the Liver of the higher Vertebrata (§ 723).

718. Whatever degree of complexity, however, prevails in the general arrangement of the elements of the Glands in higher animals, these elements are themselves everywhere the same; consisting of *follicles* that enclose the real secreting cells (Figs. 121 and 122). Now from the history of the development of Glands in

Fig. 121.*

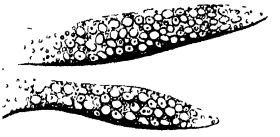
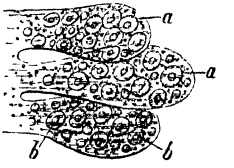


Fig. 122.†



general, it appears that the *follicles* may be considered as *parent-cells;* and that the *secreting* cells in their interior constitute a *second* generation, developed from the nuclei or germinal spots on the walls of the first. These closed cells become follicles, by opening at one extremity, either upon a neighbouring free surface, or into a canal which is prolonged from it. Thus the first rudiment of the Liver is formed by a thickening of the cellular mass in the walls of the alimentary canal, at the spot in which the hepatic duct is subsequently to discharge itself. This thickening increases, so as to form a projection upon the exterior of the canal; and soon afterwards the lining membrane dips-down into it, so that a kind of cæcum is formed, surrounded by a mass of cells, as shown in Fig. 115. The increase of the mass seems to be effected by a continual new budding-forth of cells from its peripheral portion, which takes place to a considerable extent before the cæcum in the interior begins to ramify. Gradually, however, the cells of the exterior become metamorphosed into fibrous tissue for the investment of the organ; those of the interior break-down into ducts which form continuations of the principal canal; whilst those which occupy the intervening space, and which form the bulk of the gland, seem to be developed into follicles, and to give origin to the proper secreting cells. As this is going-on, the hepatic mass is gradually removed to a distance from the wall of the alimentary canal; and the cæcum is

* Two follicles from the liver of *Carcinus mœnas* (Common Crab), with their contained secreting cells.

† Ultimate follicles of Mammary gland, with their secreting cells, *a*, *a*;—*b*, *b*, the nuclei.

of

narrowed and lengthened so as to become a mere connecting pedicle, forming, in fact, the main trunk of the hepatic duct.—The development of the Pancreas, Salivary glands, &c., seems to follow the same plan.

719. It has been pointed-out by Prof. Goodsir, that the continued development and decay of the glandular structure,—in other words, the elaboration of its secretion, may take-place in two different modes. In one class of Glands, the parent-cell, having begun to develope new cells in its interior, gives way at one point, and bursts into the excretory duct, so as to become an open follicle, instead of a closed cell: its contained or secondary cells, in the progress of their own growth, draw into themselves the matter to be eliminated from the blood, and, having attained their full term of life, burst or liquefy, so as to discharge their contents into the cavity of the follicle, whence they pass by its open orifice into the excretory duct: and a continual new production of secondary cells takes-place from the germinal spot or nucleus at the extremity of the follicle, which is here a permanent structure. In this form of gland, we may frequently observe the secreting cells existing in various stages of development within a single follicle; their size increasing, and the character of their contents becoming more distinct, in proportion to their distance from the germinal spot (which is at the blind termination of the follicle), and their consequent proximity to the outlet (Fig. 121). In some varieties of such glands, however, as in the greatly-prolonged follicles or *tubuli uriniferi* of the kidney, the production of new cells does not take-place from a single germinal spot at the extremity of the follicle, but from a number of points scattered through its entire length.—In the second type of Glandular structures, the parent-cell does not remain as a permanent follicle; but having come to maturity and formed a connection with the excretory duct, it discharges its entire contents into the latter, and then shrivels-up and disappears, to be replaced by newly-developed follicles. In each parent-cell of a gland formed upon this type, we shall find all its secondary or secreting cells at nearly the same grade of development; but the different parent-cells of which the parenchyma of the gland is composed, are in very different stages of growth at any one period, some having discharged their contents and being in progress of disappearance, whilst others are just arriving at maturity and connecting themselves with the excretory duct, others exhibiting an earlier degree of development of the secondary cells, others presenting the latter in their incipient condition, whilst others are themselves just starting into existence and as yet exhibit no traces of a second generation.—The former seems to be the usual type of the ordinary Glands; the latter is chiefly, if not entirely, to be met-with in the Spermatic glands.

2. *Of the Liver and the Bile.*

720. The Liver is more rarely absent than any other Gland, being discoverable, under some form or other, in all but the very lowest members of the Animal kingdom. Its simple condition in the lowest Mollusks has been already noticed (§ 716); and it is met-with, under an almost equally simple form, in the Star-fish. As we ascend the scale, however, we find it assuming a much greater importance, and presenting a great increase in size. This is particularly the case in the Molluscous classes; and also in the Crustacea, a class which, in mode of respiration and in general habits, bears a great resemblance to the Mollusca. In nearly all such animals, the Liver makes-up a large proportion of the mass of the body. It usually consists of a series of large follicles, which branch-out into smaller ones (Figs. 123 and 124), and of which

Fig. 123.*

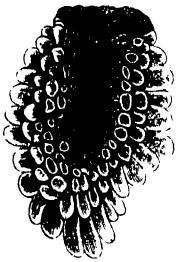


Fig. 124.†



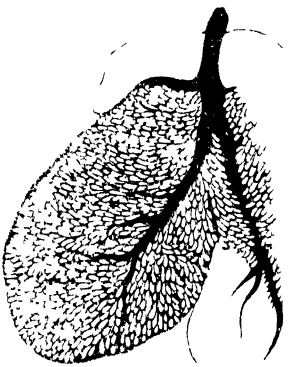
several open into one excretory duct; but these ducts remain separate, and discharge their contents into the intestine by several distinct orifices.—In Insects and other air-breathing Articulata, however, the Liver is much less developed; and its type remains much simpler. We usually find it consisting of a small number of cæcal tubuli, which open separately into the intestinal canal, just below the stomach. These tubuli are often so long, as to pass several times from one extremity of the visceral cavity to the other, being doubled upon themselves; in other instances, we find that the principal tube or canal is beset with rows of short follicles, somewhat in the manner of Fig. 118; but they never cluster together so as to form a solid glandular mass. The low develop-

* Lobule of Liver of Squilla Mantis; exterior.
† Lobule of Liver of Squilla Mantis cut open.

ment of the liver, in these animals, bears an evident relation to the high development of their respiratory apparatus; whilst, the respiration being comparatively feeble in the aquatic Mollusca and Crustacea, the development of the liver in those classes is enormous.

721. There is much difficulty in ascertaining the mode in which the elementary constituents of the Liver are arranged, in the fully-developed condition of that organ in the higher Vertebrata. At an early period of its development, as already remarked, it may be easily shown to consist, in the Fowl, of a series of distinct cæcal follicles, clustered round a projection from the intestinal canal, and opening separately into it (Fig. 115); and it is a peculiarly interesting fact, that this very condition should exist as the permanent form of the Liver, in that curious little fish, the *Amphioxus* or Lancelot, which retains the embryonic type in so many parts of its conformation. In the Tadpole, again, the distinct follicles seem very evident (Fig. 125); but here we see that the projection of the

Fig 125*



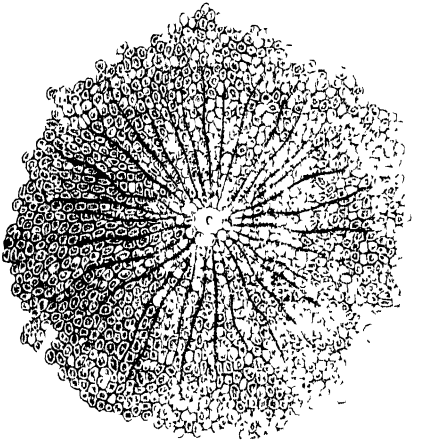
intestinal canal, instead of being a simple wide cæcum, has become extended in length and contracted in diameter, at the same time dividing and sub-dividing, so as to form an arborescent excretory duct, whose ramifications extend through the entire glandular mass. In this manner, then, is formed the complex system of hepatic

* Liver of Tadpole, showing distinct and free cæcal terminations of the biliary ducts.

ducts, which we find in the liver of the higher Vertebrata, branching-out from the main trunk. But the mode in which the ultimate ramifications of these are arranged, and their relations with the secreting cells which make-up the *parenchyma* of the gland, have not yet been fully elucidated. The following are the principal facts that have been ascertained on the subject.

722. The entire Liver is made-up of a vast number of minute *lobules*, of irregular form, but about the average size of a millet-seed. Each of these lobules contains all the elementary parts of which the entire organ is composed; namely, branches of the hepatic artery and vein, branches of the portal vein, branches of the hepatic ducts, and secreting cells. The appearance which they present when cut-into, is shown in Fig. 126; where it is seen that the secreting

Fig. 126 *



cells are packed closely together into a solid *parenchyma*, which is imperfectly divided into radiating segments by the peculiar disposition of the blood-vessels (Fig. 128). This parenchyma is minutely traversed by a capillary network, the interstices of which are entirely filled by the secreting cells (Fig. 129); and these cannot

* Transverse section of a lobule of the Human Liver, showing the arrangement of the hepatic cells in lines radiating from the *Vena centralis*, the section of which is seen at c

be shown to be inclosed by any limitary membrane resembling that of glandular tubes or follicles. The lobules are connected together in part by areolar tissue, but in great part by the anastomosis of the

Fig. 127 *

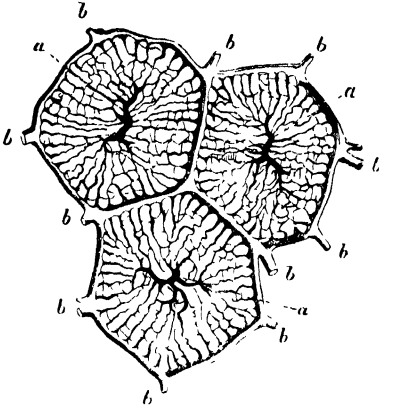


blood-vessels and hepatic ducts which supply the adjoining lobules indeed there is frequently no definite division of the glandular substance into lobules, other than that which is marked-out by the arrangement of these canals (Figs. 128 and 130). The branches of the *Hepatic Artery* are principally distributed upon the walls of the hepatic ducts, and upon the trunks and branches of the portal and hepatic veins, supplying them with their *vasa vasorum* also upon Glisson's capsule and its prolongations into the substance of the liver, which prolongations form the greatest part of the connecting structure that holds-together the several elements. There is strong reason to believe, that the blood which the liver receives from the hepatic artery is not destined to supply the materials for the biliary secretion, until it has become venous by travelling through the capillary network, in which it is subservient to the nutrition of the tissues it permeates, as it is in other parts of the systemic capillary apparatus.—The supply of blood from which the materials of the biliary secretion are chiefly drawn, is afforded by the *Vena Portæ*, which collects it as a Vein from the chylopoietic viscera, and which then subdivides as an Artery to distribute it to the different parts of the Liver. Its branches proceed to the capsules of the lobules, covering the whole *external* surface of the latter with their ramifications, and sending capillary twigs inwards, which converge towards the centre of each lobule (Fig. 128, *b*, *b*). As the principal branches of these veins ramify in the spaces between the lobules, they are termed *inter*-lobular veins.—On the

* Portion of parenchyma of the Human Liver injected, and highly magnified, showing the hepatic cells in the interspaces of the capillary network

other hand, the branches of the *Hepatic Vein* pass from the trunks to the centre of each lobule, from which they send out diverging capillary twigs (*a*, *a*) towards the circumference; and these last,

Fig. 128.*



coming into connection with the converging capillaries of the portal vein, establish a free capillary communication between the interior and the exterior of each lobule. Thus the portal blood is first distributed to its exterior, then penetrates its substance, and then, after permeating the parenchymatous substance in numerous minutely divided streams, is collected and carried-off by the hepatic vein, of which a twig originates in the centre of each lobule. Owing to the peculiar position of the branches of the hepatic vein in the centre of each lobule, the lobules are appended to its main trunks almost in the manner of leaves upon a stem (Fig. 129).— The precise relation of the capillaries of the hepatic artery with those of the portal and venous systems, has not yet been well ascertained; but there seems reason to believe, with Mr. Kiernan, that the arterial capillaries discharge themselves into the ultimate ramifications of the portal vein; and that thus the blood of the former, having become venous by transmission through the nutritive capillaries of the liver, mingles with the other venous blood

* Horizontal section of three superficial lobules of the Liver, showing the two principal systems of blood-vessels; *a*, *a*, *intra*-lobular veins, proceeding from the Hepatic veins; *b*, *b*, *inter*-lobular plexus, formed by branches of the Portal veins.

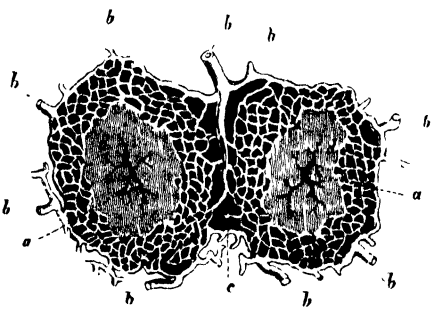
collected by the vena portæ, to supply the materials of the secretory action, which are eliminated during its passage into the hepatic vein.

Fig. 129.*



723. The *Hepatic Ducts* also seem to form a plexus which surrounds the lobules, connecting them together, and sending branches towards the interior of each (Fig. 130). The mode in which they

Fig. 130.†



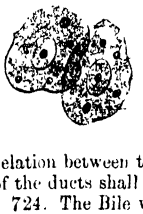
terminate, however, and the precise relation in which they stand to the hepatic cells, which form nearly the entire parenchyma of

* Connection of the lobules of the Liver with the Hepatic vein:—*a*, trunk of the vein; *b*, *b*, lobules depending from its branches, like leaves on a tree, the centre of each being occupied by a venous twig,—the Intralobular Vein.

† Horizontal section of two superficial lobules, showing the interlobular plexus of Biliary Ducts:—*a*, *a*, intralobular veins; *b*, *b*, trunks of biliary ducts, proceeding from the plexus which traverses the lobules; *c*, interlobular tissue; *d*, parenchyma of the lobules.

the Gland, has not yet been completely elucidated. It is maintained by some that the tubular plexus extends throughout the substance of the lobule, filling-up the entire space not occupied by the blood-vessels (its membranous wall, however, being with difficulty traceable, owing to its extreme tenuity); and that the hepatic cells are contained within it, as within the follicles or tubes of ordinary glands. By others, on the contrary, it is considered that the cellular parenchyma of the liver is comparable to that of the Peyerian bodies (§ 496), or of the Malpighian bodies of the spleen (§ 506); and that the hepatic ducts do not enter far into the lobule, but only receive the products of its secreting action by the transmission of these through the successive cells from its interior to its exterior.—The Hepatic Cells (which are easily obtained in a separate condition by scraping a piece of fresh liver) are of a flattened spheroidal or polygonal form; and their diameter is usually from 1-800th to 1-1600th of an inch. Each cell presents a distinct nucleus, and it is usually around this that the yellowish hue of the cell is the deepest. The cavity of the cell is chiefly occupied by biliary matter, much of which is in the condition of fine granular particles too minute to be measured. In the midst of these, there are usually one or two large adipose globules, or five or six small ones (Fig. 131); but the amount of this fatty matter is liable to great variation (§ 754). The biliary matter which these cells contain, marks them out as the real agents in the secreting process; this process consisting, it is evident, in the growth of the hepatic cells, which, in the course of their development, eliminate from the blood the biliary matter, for which they have a special affinity. The mode in which the particles thus eliminated are discharged into the hepatic ducts, to be by them conveyed to the intestine, cannot be fully understood, until the relation between the secreting cells and the ultimate ramifications of the ducts shall have been more precisely determined.

Fig. 131 *



724. The Bile which has been secreted by the hepatic cells, and which has found its way into the ramifications of the hepatic ducts, may be directly conveyed by the trunk of the latter into the intestine, or it may regurgitate along the cystic duct into the gall-bladder. It is probable that the secreting process is constantly going-on; although, as in other cases, it may vary in its degree of activity at different times. When the process of digestion is taking place, and the small intestine is filled with chyme, there is probably an uninterrupted flow of bile into its cavity; but when the intestine is empty, the bile seems not to be admitted into it, but

* Glandular cells of Liver:—*a*, nucleus; *b*, nucleolus; *c*, adipose particles.

rather to flow-back into the gall-bladder, in which it is stored-up, as in a reservoir, until the time when it may be needed. In this reservoir it undergoes a certain degree of concentration, by the absorption of its watery part; and it also becomes mixed with a large proportion of mucus, which is secreted by the walls of the gall-bladder.—As the analyses of Bile have been chiefly made upon the fluid obtained from this receptacle, they probably over-estimate the proportion of solid matter contained in this secretion; which is usually stated at from 8 to 9½ per cent. Of this solid matter, about a tenth consists of alkaline and earthy salts, corresponding with those of the blood; whilst the remainder is made-up of organic constituents. These are very readily decomposed, and enter into new combinations with the substances employed to separate them; so that different Chemists, by employing different means of analysis, have obtained results which seem far from conformable to each other. The researches of Strecker, however, confirmed by those of Lehmann, appear to have now satisfactorily demonstrated, that the proper biliary matter consists of a combination of two resinoid acids, the *Glycocholic* (which is the *cholic* of Strecker and of many former chemists), and the *Taurocholic* (which is the *cholcic* of Strecker, and is nearly the same with the *bilin* of other chemists), with a soda-base. These are formed, according to Lehmann, by the 'conjugation' of a resinoid acid common to both of them, namely, *Cholic* acid,—whose composition is 48 Carbon, 39 Hydrogen, 9 Oxygen,—with *glycine* (gelatin-sugar) and *taurine* respectively. The latter substance is remarkable for the large proportion of sulphur—no less than 25 per cent.—which it contains; so that the proportion of taurocholic to glycocholic acid, which differs greatly in different animals, may be estimated by the amount of sulphur present in the mixture of the two. Besides a variable quantity of the ordinary fatty acids, Bile also contains a non-saponifiable fatty matter termed *Cholesterin;* this is a white crystallizable substance, somewhat resembling spermaceti, free from taste and odour, and composed almost entirely of carbon and hydrogen; its formula is 36 Carbon, 32 Hydrogen, and 1 Oxygen. The proportion of Cholesterin in healthy bile appears to be very small, and it is held in solution by the preceding ingredients; but in many disordered states, and especially in disease of the gall-bladder, this component is present in much larger amount; and it usually forms the principal, if not the sole ingredient in biliary concretions.—The Colouring matter of Bile is a substance distinct from the preceding; that of the Ox and other graminivorous animals appears to be identical, or nearly so, with the chlorophyll of the leaves on which they feed; but that of Human bile seems to possess different properties, and to be derived from the proper constituents of the blood. This also occasionally accumulates so as to form concretions which consist of little else.

725. Regarding the destination and purposes of this secretion in the Animal economy, the following may be considered as a tolerably complete summary; though it is impossible to speak with precision on some points, since the organic constituents of the Bile are liable to be so easily altered by various reagents, that they are with difficulty recognized.—A portion of the Bile unquestionably passes off, in Man and most other animals, with the fæces; this portion, which includes the colouring matter, is probably that which would be most injurious if retained in the blood, and is most purely *excrementitious*. In bilious diarrhœa, and under the influence of purgatives, especially mercurials, a large quantity of bile is discharged *per anum*, apparently almost unchanged. But in the healthy state, a portion, at least, of the soapy compound seems destined for re-absorption. Just as ox-gall is commonly used to remove grease-spots, by its solvent power for fatty matter, so does the bile seem to act in the living body, by rendering soluble the fatty matters of the food, and thus enabling them to be absorbed by the lacteals (§ 479). The fatty matter of the bile, when re-absorbed with that of the newly-ingested food, is probably, like it, carried-off by the respiratory process: but as the biliary matter cannot supply more than a small proportion of the amount of carbon eliminated from the lungs in the form of carbonic acid, it cannot be (as supposed by Liebig) the chief fuel of the process of combustion which is kept-up through the agency of those organs. The secreting action of the Liver, however, by which a certain product is entirely separated from the blood, constitutes only a part of the action of that organ; since, as already shown (§ 493), the changes which it effects in the alimentary materials newly introduced into the current of the circulation, are at least equally important; and these changes are in great part subservient to the preparation of the respiratory *pabulum*. A large part of the bulk of the Liver, in many of the lower animals, is made-up of oleaginous matter; which appears to accumulate in the hepatic cells, giving them almost the character of fat-cells, in proportion as the respiratory function is inactive. Thus the liver is very large and fatty in Mollusca and Crustacea; whilst in Insects, on the other hand, it is comparatively undeveloped. In Fishes, again, it is rich in oily matter, but in Mammals it is much less fatty in the state of health; whilst in the liver of Birds, scarcely any traces of fat are to be found.

726. The elements of the Bile may be altogether supplied by the disintegration of the tissues; and this must certainly be the case, when the amount of food taken is no more than enough to supply the *waste* of the system. We may regard it, then, as one office of the Liver, to remove from the blood, and to convert into a form suitable for oxygenation by the respiratory process, such products of that disintegration as are rich in carbon and hydrogen. It may be pretty certainly affirmed, however, that biliary matter does not

pre-exist *as such* in the blood, but that its elements must be originally present there under some more pernicious form. For it is found that the total suspension of the secreting action of the Liver, whereby the excrementitious matter is left to accumulate in the blood, has a much more prejudicial effect upon the system, than the re-absorption of Bile after it has been secreted, in consequence of an obstruction to its discharge through the ductus choledochus; so that it may be inferred that the noxious products of the disintegration of the tissues are transformed into the comparatively-innocent components of Bile, in the very act of secretion.—But there can be little doubt that the Liver has also for its office, to draw-off from the blood any superfluity which may exist in the non-azotized compounds derived from the food, beyond the amount that is requisite for the supply of the respiratory process, or that can be deposited as fat. For we continually witness the results of habitual excess in the ingestion of such substances, in producing that state of the system commonly termed *bilious;* of which all the symptoms are referable to the accumulation of the elements of the bile in the blood, and the consequent deterioration in the purity of the circulating fluid. Where a tendency to such a state exists, proper means should be taken to stimulate the liver to increased activity; but the chief reliance should be placed on the avoidance of those articles of diet which contain a large proportion of hydrocarbon, and on abstinence from superfluous nutriment of any description.

3. *Of the Kidneys and the Urine.*

727. The Kidneys are perhaps the most purely *excreting* organs in the body; their function being to separate from the blood certain matters that would be injurious to it if retained, and these matters being destined to immediate and complete removal from the system. We have seen that, in the Lungs, the excretion of Carbonic acid is made subservient to the absorption of Oxygen; and the separation of a fatty acid from the blood, which is effected by the Liver, is a means of introducing a new supply of fatty matter into the system. There is no ulterior purpose of this kind in the secreting action of the Kidney; the product of which is invariably conveyed directly to an outlet, by which it may be discharged from the body. Some traces of Urinary organs may be detected in most of the higher Invertebrata; but it is in Fishes that they first present a considerable development; and in ascending through the Vertebrated series, we find them rapidly increasing in the complexity of their organization, and in their functional importance, although their size and extent are not so great. In Fishes, the Kidneys very commonly extend through the whole length of the abdomen; and they consist of tufts of uniform-sized tubules, which shoot-out transversely at intervals from the long ureter, and which are connected-together by a loose web of

areolar tissue that supports the network of vessels distributed upon their walls. This condition of the Urinary organs is very analogous to that of the Corpus Wolffianum, or temporary kidney of the embryo of higher animals (Fig 132, *f*) A similar condition is found in the true Kidney of higher animals at an early grade of development (as shown in Fig 133), the tubuli uriniferi being short and straight In their more advanced condition, however, they become long and convoluted, and the ramifications of the capillary vessels come into very close relation with them (Fig 134) It is in the higher Reptiles, that we first meet with the distinction between the *cortical* and the *medullary* substances the former being the part in which the blood vessels are most

Fig 132 *

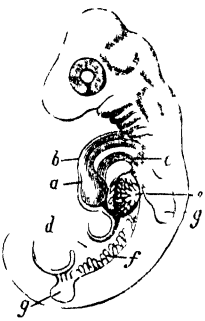


Fig 133 †



piously distributed, and in which the tubuli have the most convoluted arrangement and the latter consisting chiefly of straight



* Embryo of Green Lizard —*a* heart *i* duplex aorta *c* vena cava *i* intestine *e*, liver *f* rudiment of Wolffian body *j*, rudiments of extremities

† Kidney of fœtal Boa —the urinary tubes as yet short and straight

‡ Portion of Kidney from Coluber —*a*, *a*, vascular trunk *b*, *b*, ureter *c*, *c*, converging fasciculi of tubuli uriniferi

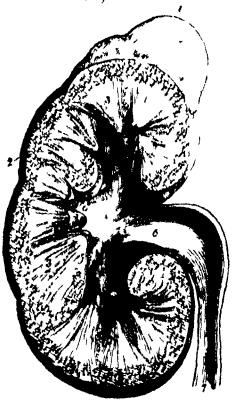
tubuli, converging towards the points at which they discharge themselves into the ureter (Fig. 135). The bundles of tubuli and their vascular plexuses remain distinct, however, in Birds and in the lower Mammalia, so as to give to the whole gland a lobulated character; but in the Human Kidney (Fig. 136) they come into closer contact; and the vascular connection between the plexuses of the different bundles is such, as to prevent any ostensible separation into distinct lobes.

Fig. 135.*



728. The secreting apparatus of the kidney consists of the *tubuli uriniferi* and of the epithelial cells by which they are lined. These, with the blood-vessels which supply the materials of the secretion, are imbedded in a 'stroma' composed of interlacing fibres, which is more abundant in the medullary than in the cortical substance, but which is condensed at the surface of the gland into a continuous membrane, which is loosely connected with the proper capsule. In passing outwards from the papillæ (Fig. 136, 4), the tubuli increase in number by divarication to a considerable extent (Fig. 138, B), their diameter remaining about the same. When they arrive in the cortical substance, they seem not only to become much convoluted, but also to form a sort of plexus with free extremities here and there; the number of such free extremities, however, does not seem to be nearly equal to that of the uriniferous

Fig. 136.†



* Pyramidal fasciculi of Tubuli Uriniferi of Bird, terminating in one of the branches of the ureter.

† A section of the Kidney, surmounted by the supra-renal capsule; the swellings upon the surface mark the original constitution of the organ, as made up of distinct lobes.—1. The supra-renal capsule; 2. the cortical portion of the kidney; 3, 3. its medullary portion, consisting of cones; 4, 4. two of the papillæ projecting into their corresponding calices; 5, 5, 5. the three infundibula; the middle 5 is situated in the mouth of a calyx; 6. the pelvis; 7. the ureter.

tubes themselves. The character of the epithelium which lines the tubuli, varies in different parts of their course. In the tubes

Fig. 137.*

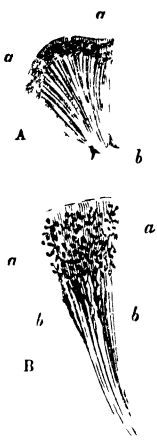
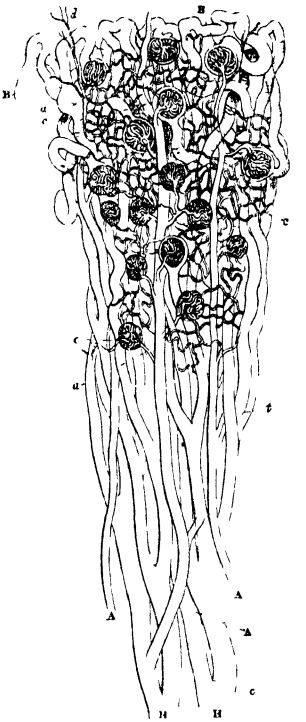


Fig. 138.†



of the cortical substance, the cells are spheroidal in their form, and project considerably into the cavity of the tube; but in the straight tubes of the medullary substance, the cells are flattened and polygonal (Fig. 139), and lie close against the wall of the tube. Each cell contains a nucleus; and in its interior there is ordinarily to

* Portion of the Kidney of a new-born infant:—A, natural size; *a*, *a*, Corpora Malpighiana, as dispersed points in the cortical substance; *b*, papilla. B, a smaller part magnified; *a*, *a*, Corpora Malpighiana; *b*, *b*, tubuli uriniferi.

† Plan of the structure of the Kidney:—A, A, primary branches of the renal artery; *a*, *a*, twigs proceeding to Malpighian bodies; B, B, Malpighian bodies; *c*, *c*, capillary network, partly formed by efferent vessels from Malpighian bodies, and partly by twigs, *d*, of the renal artery, which do not pass into them; H, H, larger tubuli uriniferi dividing dichotomously; *t*, a smaller tube.

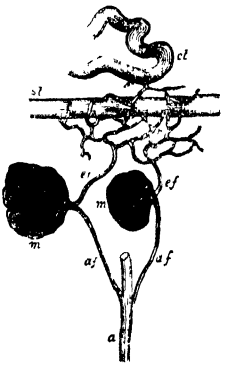
be seen a little finely-granular matter, with a few minute fat-globules clustered round the nucleus. The cell-wall is very thin; and there is strong reason to believe that it gives passage to the components of the urinary secretion, so that these are continually escaping into the tubes by transudation, without the death of the cells which secreted them.

Fig. 139.*



729. Besides its proper secreting structure, the Kidney contains an apparatus of a very peculiar description, which appears specially destined for the separation of the superfluous *fluid* of the system. When a section of the Kidney is slightly magnified (Fig. 137, B), the cut surface is seen to be studded by a number of little dark points; each of which, when examined under a higher magnifying power, is found to consist of a knot of minute blood-vessels, formed by the convolutions of thin-walled capillaries (Fig. 138, B B). It has been shown by Mr. Bowman, that each one of these knots (called Malpighian bodies, after their discoverer) is included in a flask-like capsular dilatation, connected with one of the tubuli uriniferi; and that it is directly supplied by a branch of the renal artery (Figs. 138, *aa*, and 140, *af*); which, upon piercing the capsule, subdivides into a group of capillaries; and these, after forming the convoluted tuft, coalesce into a single efferent trunk (*ef*), which may be considered as representing (in a small way) the vena portæ. For the efferent trunks of the Malpighian bodies discharge their blood into the capillary plexus (Fig. 138, *c*, *c*), which surrounds the tubuli uriniferi, and from which the solid matter of the urinary secretion is elaborated; just as the vena portæ supplies the capillary plexus from which the biliary secretion is elaborated in the liver. In Reptiles (in which, as in Fishes, the kidney is partly supplied by the hepatic portal system), the efferent

Fig. 140.†



* Epithelial lining of one of the Tubuli Uriniferi.

† Distribution of the Renal vessels, from Kidney of Horse:—*a*, branch of Renal artery; *af*, afferent vessel; *m*, *m*, Malpighian tufts; *ef*, *ef*, efferent vessels: *p*, vascular plexus surrounding the tubes; *st*, straight tube; *cl*, convoluted tube.

vessels of the Malpighian bodies unite with branches of the portal vein to form the secreting plexus around the tubuli uriniferi; and even in Birds this arrangement still seems to prevail to a certain extent. Thus all the blood which the secreting plexus receives, has already passed, in each case, through a set of capillaries within or without the organ; those, namely, of the Malpighian bodies, or those of the parts supplying the general Portal system.—The special purpose of the Malpighian bodies appears to be, to allow of the transudation of the *water* of the blood, which is filtered-off (so to speak) through the thin walls of their capillaries, and thus passes into the tubuli uriniferi. It is well known that the fluid and the solid constituents of the urinary secretion bear no constant relation to each other; the amount of fluid depending mainly upon the degree of fulness of the blood-vessels, whilst the amount of solid matter is proportionate, as we shall presently see, to the previous *waste* of the tissues. The quantity of fluid in the blood-vessels is governed by the relative amount that has been absorbed and that which has been exhaled from the skin; so that the quantity to be drawn-off by the Kidneys is increased, either by augmented absorption, or by diminished exhalation. The Malpighian bodies seem to act the part of a system of regulating valves; permitting the transudation of only enough fluid to dissolve the solid matter, when there is no superfluity of water in the vessels; but allowing the escape of an almost unlimited amount of it, when increased imbibition has rendered the vessels unusually turgid.

730. The average amount of Urine excreted in twenty-four hours, by adults who do not drink more than the wants of nature require, is probably from 30 to 40 oz.; and its average specific gravity may be about 1020. The quantity of fluid is usually less, and the specific gravity of the secretion consequently greater, in summer than in winter; on account of the larger proportion of fluid exhaled by the skin during the former season. The quantity of solid matter has been found to vary, within the limits of ordinary health, from 2 to 7 per cent.; and the extent of variation in disease is doubtless much greater. About one-third of the solid matter is made-up of alkaline and earthy salts, and the remainder consists of organic compounds. The salts are partly those of the blood, which will not be separated during the transudation of the serum through the membranous walls of the Malpighian capillaries, although the albuminous matter is kept-back (§ 196). But there is a much larger proportion of the alkaline and earthy phosphates in the urine, than is present in the blood; and this is liable to a further increase under circumstances to be presently alluded-to.—The urine is normally acid, but the degree of its acidity is continually changing, and is considerably affected by food; being augmented by vegetable, and decreased by animal food. This is due to dif-

ferences, not only in the amount of acid generated, but also in that of bases present to neutralize them. The ordinary acid reaction appears to be due, not to the presence of any free acid, but to the conversion of the *basic* phosphate of soda into the *acid* phosphate, by the subtraction of a part of the base, which happens when uric, hippuric, lactic, or other free acids come into relation with the former substance. Now a Herbivorous regimen supplies a large quantity of alkaline and earthy bases, in combination with citric, tartaric, oxalic, and other organic acids; these are reduced to the state of carbonates by the decomposition of their acids within the body; and the quantity of the sulphuric, phosphoric, and uric acids produced within the body (§ 737) not being sufficient to neutralize the bases, the urine has an alkaline reaction. On the other hand, a Carnivorous regimen supplies but a small quantity of the alkaline bases, and a large amount of acidifiable materials; so that, the acids produced in the system being more than sufficient to neutralize the bases, the urine has an acid reaction. Moreover, it has been shown by Dr. Bence Jones, that when the acidity of the stomach is at its maximum (which is the case soon after the ingestion of food), that of the urine decreases, so that, from three to five hours after a meal, the urine is often alkaline; whilst, on the other hand, after a fast of some hours, when the acidity of the stomach is at its minimum, that of the urine is at its maximum.

731. The organic compounds present in the Urinary secretion (in its healthy state at least) are undoubtedly the result of the *waste* or disintegration of the animal fabric; as well as (in certain cases) of the decomposition of constituents of the blood, which have never undergone conversion into organized tissue. Their unfitness to be retained within the system, is proved by the fatal results which speedily ensue when their elimination by the secreting process receives a check; and also by the *crystalline* form in which the most characteristic of them present themselves,—such a form being altogether incompatible with the possession of plastic or organizable properties. Various well-defined compounds present themselves in the Urine of different classes of animals; and they are nearly all peculiarly rich in Nitrogen and deficient in Carbon, as compared with the Albuminous compounds. Thus, whilst the proportion of Nitrogen in Albumen is (by weight) as 1:6·24 of the whole, it is in Urea as 1:2·14, in Allantoin as 1:2·21, in Creatine as 1:2·69, in Uric acid as 1:3·00, and in Creatinine as 1:3·12. The chief exception is in the case of Hippuric acid, which is discharged largely by herbivorous animals, and in which the proportion of Nitrogen is as 1:12·14. On the other hand, whilst the proportion of Carbon in Albumen is as 1·1·80, it is in Creatinine as 1:2·35, in Creatine as 1:2·75, in Uric Acid as 1:9·80, in Allantoin 1:3·87, and in Urea as 1:5·00. Here, again, Hippuric acid is exceptional; for its Carbon is as 1·1·57 of the whole, or in larger

proportion than in Albumen.—We may say, then, that the characteristic components of the Urinary secretion are such products of the waste of the azotized tissues, as, from containing Nitrogen in large proportion, are not adapted for elimination, either by the respiratory process, or by the biliary excretion. The chief exception is in the case of Hippuric acid; and the large proportion of carbon and the small proportion of nitrogen contained in this substance, appear due to the great excess of non-azotized compounds in the food of the animals voiding it. The Colouring matter of the Urine is also remarkable for its very large proportion of carbon, and its low per-centage of nitrogen.

732. Of the compounds just enumerated, the most important, in Man, is that which is named *Urea*. It exists in urine in a state of perfect solution; and may be readily separated from it in the form of transparent colourless crystals, which have a faint and peculiar but not urinous odour. In its ultimate composition it is identical with Cyanate of Ammonia, being made-up of 2 Carbon, 4 Hydrogen, 2 Nitrogen, and 2 Oxygen,—a formula much more simple than that of almost any other organic substance. The amount of Urea in the urine is liable to very great variation, in accordance with the degree in which the disintegrating process has been taking-place in the solid fabric, and also in conformity with the amount of azotized matter which has been taken-in as food. Supposing that the latter were so precisely adjusted to the wants of the system, as to supply only that which is required for its maintenance, we might then measure the amount of previous *waste*, by the quantity of Urea present in the urine. There can be no doubt as to the fact, that, other things being equal, the amount of Urea is greatly increased by any unusual exertion of the Muscular system; but such an increase cannot be invariably, or even usually, attributed to this cause; since it is equally certain, that any superfluity in the amount of azotized matter received into the blood, must be drawn-off by the urinary excretion, and thus that an increase in the quantity of urea may be occasioned by an excessive use of albuminous or gelatinous compounds as articles of food. The average proportion of Urea, under ordinary circumstances as to diet and exercise, seems to be from 20 to 35 parts in 1000; but it may be raised to 45 parts by violent exercise, and to 53 parts by an exclusively animal diet; whilst it may fall as low as from 12 to 15 parts, when the diet is deficient in azotized matter. The total daily excretion of Urea in adult males seems to average about 430 grains, and that of females nearly 300 grains; but these averages may be widely departed-from, on the side either of excess or diminution, according to the circumstances already noticed. It is interesting to observe, that children of eight years old excrete, on the average, *half* as much Urea as adults; whilst, in very old persons, the quantity sinks to *one-third*, or even less. In

tion of the azotized matters that are undergoing decomposition; hence such an increase may occur, either from deficient respiratory activity, or from an excess in the amount of the substances to be oxidated.

734. Although *Hippuric* acid has been usually supposed to be restricted to the urine of Herbivorous animals (in which it replaces uric acid), yet there seems reason to regard it as a normal component of the urine of Man; its amount in the state of health, however, is extremely small. Its composition and properties are very different from those of uric acid. When pure, it forms long transparent four-sided prisms; it is soluble in 400 parts of cold water, and dissolves readily at a boiling heat; and it has a strong acid reaction, with a bitterish taste. It is composed of 18 Carbon, 8 Hydrogen, 1 Nitrogen, and 5 Oxygen, with 1 equiv. of Water. When exposed to a high temperature, or subjected to the putrefactive process, it is partly converted into Benzoic acid; and it is on the presence of the latter in putrefied Human urine, that the belief in the existence of Hippuric acid in the same fluid when fresh is chiefly grounded.—The large proportion of Carbon in this substance, indicates that it is a product of imperfect oxidation: hence we can account, on the one hand, for its presence in the urine of herbivorous animals, whose food contains so large a proportion of substances requiring oxygen for their combustion; and, on the other, for its appearance in greatly-increased proportion in Human urine, when obstructed action in either of the other great emunctories throws upon the kidneys an unusually-large proportion of carbonaceous matters for elimination.

735. Much discussion has taken-place, as to the normal presence of *Lactic* acid in the urine; and the question cannot even now be regarded as completely determined. It is certain that the peculiar crystalline compound procurable by treating the urine with zinc in solution, is not (as was formerly maintained) a lactate of zinc, but that its composition is altogether different, as will be presently explained. On the other hand, it appears from the researches of Lehmann and others, that lactic acid may present itself in small quantity in healthy urine; and that its quantity may be increased under such conditions, as either tend to augment the quantity of lactic acid in the blood, or to obstruct its elimination by the respiratory process. Thus an excess of farinaceous food, which furnishes sugar and lactic acid faster than they can be thrown-off as carbonic acid and water; or an excess of exertion of the muscles, of whose disintegration lactic acid appears to be one of the results; or pulmonary diseases, which interfere with the normal aeration of the blood; all favour the appearance of lactic acid in the urine. It seems to be constant in herbivorous animals, and in patients suffering under chronic bronchitis, pulmonary emphysema, and similar disorders. —The urine of Man more uniformly contains, however, two sub-

stances termed *Creatine* and *Creatinine;* which seem to be the result of the degeneration of the muscles, as they may be obtained from the juice of raw flesh. The former of these, which occurs in largest amount, is a neutral substance, crystallizing in long prisms, sparingly soluble in cold water, but dissolving readily in warm. By the action of strong acids, creatine may be readily converted into creatinine, which only differs from it in composition by containing two proportionals less of the elements of water, but is a substance of very different chemical relations, having a strong alkaline reaction, and serving as a powerful organic base to acids. When long boiled with caustic baryta, creatinine is gradually resolved into urea; and thus it would seem as if these two substances hold an intermediate position between the components of the organized tissues, and the urea which may be considered as the ultimate product of their metamorphosis within the body. The peculiar crystalline compound just referred-to as having been formerly supposed to be lactate of zinc, has been shown to be really formed by a combination of zinc with a compound of creatine and creatinine.

736. Of the substances ranked under the head of *Extractive Matters*, little is definitely known; it appears, however, from recent researches, that they are peculiarly rich in carbon, and that they are liable to be greatly augmented, either by an excess of non-azotized matter in the food, or by any impediment to the action of the liver or lungs. The *Urine-pigment* seems to be distinguishable as a definite compound; and although there is still much uncertainty as to its precise character, there is no doubt as to the very large proportion of carbon it contains. The action of hydrochloric acid on this pigment produces the substance called *purpurine*, which sometimes gives a deep colour to the sediment of urate of ammonia. The ordinary colouring-matter of bile often presents itself in the urine in cases of jaundice; and, as Dr. Golding Bird has pointed-out, there is a close similarity in composition between these three coloured compounds, indicating a derivation from the same source, probably the hæmatin of the blood. A *sulphur-extractive* has also been obtained from the urine; in which (as in the bile) there is a considerable proportion of free sulphur.

737. The Urine also contains a considerable amount of Saline matter, of which the acids as well as the bases are derived from the mineral kingdom; and the excretion of them, after they have served their purpose in the economy, appears to be one of the chief functions of the Kidney. Of these, a part may find their way directly into the urine from the serum of the blood, when its water is being filtered-off (so to speak) through the walls of the Malpighian capillaries; for although, from the peculiar properties of animal membranes (§ 196), the albuminous constituents of the serum are held-back, the saline matter, which is in a state of perfect

solution, must pass with the water. This is probably the chief source of the large quantity of the muriates of soda and ammonia contained in the urine. But the urinary secretion seems to be specially destined to eliminate those saline compounds, which are formed by the acidification of the Sulphur and Phosphorus taken in with the protein-compounds as food. These substances are united with Oxygen in the system, and are thus converted into Sulphuric and Phosphoric acids; which acids unite with alkaline bases, that were ingested in combination with Citric, Tartaric, Oxalic, and other organic acids; the latter undergoing decomposition within the system, and leaving the bases ready to unite with others.

738. The Alkaline *Sulphates*, whether taken-in as such, or formed in the manner now described, are soluble enough to be always passed-off in the fluid form; but this is not uniformly the case with the *Phosphates*, which are frequently deposited as sediments of a dead-white aspect, sometimes crystalline, and sometimes wholly or partly amorphous. The crystalline sediment consists of the *triple phosphate*, or phosphate of ammonia and magnesia; the amorphous contains an admixture of the phosphate of lime. The urine, when these are deposited, is usually alkaline, sometimes very decidedly so; and there is reason to think that, in many cases, this alkaline character, and the deposit of phosphatic sediments, are due to an alkaline secretion from the walls of the bladder and urinary passages, which results from an irritable state of their membrane,—the urine, as secreted by the kidney, having its usual properties. That an alkaline condition of the urine, resulting from the presence of an unusual amount of *bases*, is capable of producing a phosphatic deposit, is shown by the simple experiment of adding ammonia to healthy urine, which will occasion a precipitation of the triple phosphate.

739. But there can be little doubt that a frequent cause of such deposits, is excessive production of the phosphatic salts, arising from the increased waste or disintegration of Nervous matter, which takes-place when the Nervous system is in a state of unusual activity, either from intense thought, from prolonged exertion, or from continued anxiety. The general principles already set-forth, in regard to the dependence of the functional activity of the Nervous Centres upon a supply of arterialized blood (§ 384), show the probability that every act of theirs involves the oxygenation of a certain quantity of nervous-matter. In this oxygenation, phosphoric acid will be produced, owing to the large amount of phosphorus contained in the nervous matter; and this will unite in part with ammonia, which is perhaps set-free by the same metamorphosis, or is derived from other sources; and in part with the fixed alkalies derived from the food. The experience of every studious man must have shown him (if he make any observations

on the matter at all) the frequent coincidence between the presence of phosphatic deposits in his urine, and an excess of mental labour; and there are many instances on record, in which the periodical recurrence of the latter has been so invariably followed by the recurrence of the former, that no reasonable doubt can exist as to their mutual connection.

740. It is very important for the successful treatment of those Urinary deposits which consist of the normal elements of the Urine,—namely, Lithic acid or Lithates, and the Phosphates,—that the leading facts already stated should be borne continually in mind. In the first place, these sediments may depend upon the general condition of the fluid, and not upon any excess in the constituents of which *they* are composed; thus a lithic deposit may result from the presence of an excess of some other acid in the urine; and a phosphatic sediment may be produced by the excess of bases. In such cases, then, our treatment should be directed, not to diminish the quantity of the peculiar constituents of the deposits, but to rectify the state of the Urine on which their precipitation depends. But, in the second place, the sediments may be present in such great amount, as to indicate that their constituents are present in the urine to an excessive degree; and our treatment must then be directed towards the diminution of the quantity produced. Thus the tendency to lithic acid deposit may be frequently cured, by simply diminishing the quantity of azotized matter in the food; and the undue formation of the phosphates may be often kept in check by that mental repose, which is peculiarly required after long-continued and severe exercise of the intellectual faculties, or strong excitement of the feelings.

741. There is no doubt whatever, that the total suspension of the Urinary secretion is productive of rapidly-fatal results, from the accumulation of the elements of the secretion in the blood; and it would appear that the tissue on which their presence in the circulating fluid exerts the most injurious effects, is the Nervous. It is probable that Urea is the substance which is most directly concerned in producing the noxious influence; though there is reason to believe that it must undergo some change by decomposition (perhaps into Carbonate of Ammonia) in order to produce a poisonous effect. We see an effort made by the system (so to speak) to get rid of retained urea, in those cases in which a discharge of urinous fluid takes place by unusual channels, such as from the mucous membrane of the stomach, the mamma, the umbilicus, the nose, &c., when the usual secreting action of the kidney has been suspended. Although the accounts of such cases have been treated with ridicule by some Physiologists, yet there seems no valid reason to discredit them, when it is borne in mind that, in persons who have died from the complete suspension of the secretion, effusions containing urea have been found in the serous cavities of the trunk,

and in the ventricles of the brain. The poisonous influence of an accumulation of urea in the blood, when strongly exerted, produces in the first instance irregular or convulsive movements, which are dependent upon irritation of the Spinal system of nerves; then loss of consciousness, depending upon the suspension of the powers of the Brain; and lastly, complete suspension of the powers of the spinal system, so that the ordinary reflex actions cease, and life becomes extinct from the stoppage of the respiratory movements (§ 688). There is reason to believe that many convulsive motions for which no obvious cause can be assigned, have their origin in a disordered condition of the blood, resulting from imperfect elimination of Urea; thus it has been ascertained that, in several cases of puerperal convulsions, urea was present in the blood; the functional power of the kidney being diminished by chronic disease. It is especially to be noticed, that most of the cases in which the urinary secretion is discharged through some irregular channel, occur in persons who have been subject to those convulsive affections which are commonly designated as *hysterical;* and that the discharge of a large quantity of urine through the natural channel, is often the termination of an hysterical paroxysm. It is desirable, therefore, that in all such obscure cases, the state of the urinary secretion should be carefully looked-to.

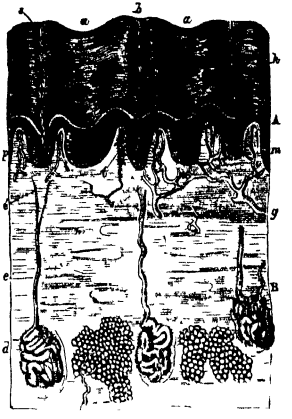
4. *Of the Cutaneous and Intestinal Glandulæ.*

742. The Glandulæ which are disposed in the substance of the Skin, and in the walls of the Intestinal canal, although individually minute, make-up by their aggregation an excreting apparatus of no mean importance. The Skin is the seat of two processes in particular; one of which is destined to free the blood from a large quantity of fluid; and the other to draw-off a considerable amount of solid matter. To effect these processes, we meet with two distinct classes of glandulæ in its substance; the Sudoriparous or sweat-glands, and the Sebaceous or oil-glands. They are both formed, however, upon the same simple plan; and can frequently be distinguished only by the nature of their secreted product.

743. The *Sudoriparous* or perspiratory glandulæ form small oval or globular masses, situated in the deepest layer of the cutis, in almost every part of the surface of the body (Fig. 141, *d*). Each is formed by the convolution of a single tube; which thence runs towards the surface as the efferent duct, making numerous spiral turns in its passage through the epidermis, and issuing from its surface rather obliquely, so that its orifice is covered by a sort of little valve of scarf-skin, which is lifted-up as the fluid issues from it. The convoluted knot of which the gland consists, is copiously supplied with blood-vessels. On the palm of the hand, the sole of the foot, and the extremities of the fingers, the apertures of the

perspiratory ducts are visible to the naked eye, being situated at regular distances along the little ridges of sensory papillæ, and giving to the latter the appearance of being crossed by transverse lines. According to Mr. Erasmus Wilson, as many as 3528 of these glandulæ exist in a square inch of surface on the palm of the hand; and as every tube, when straightened-out, is about a quarter of an inch in length, it follows that in a square inch of skin from the palm of the hand, there exists a length of tube equal to 882 inches, or 73½ feet. The number of glandulæ in other parts of the skin is sometimes greater, but generally less than this; and according to Mr. Wilson, about 2800 may be taken as the average number of pores in each square inch throughout the body. Now the number of square inches of surface, in a Man of ordinary stature, is about 2500; the number of pores, therefore, is *seven millions;* and the number of inches of perspiratory tubing would thus be 1,750,000, or 145,833 feet, or 48,611 yards, or nearly *twenty-eight miles.*

Fig. 141.*



744. From this extensive system of glandulæ, a secretion of watery fluid is continually taking-place; and a considerable amount of solid matter also is drawn-off by the epithelium-cells that line the tubuli. Under ordinary circumstances, the fluid is carried-off in the state of vapour, forming the *insensible* perspiration; and it is only when its amount is considerably increased, or when the surrounding air is already so loaded with moisture as to be incapable of receiving more, that the fluid remains in the form of *sensible* perspiration upon the surface of the skin. It is difficult to estimate the proportion of solid matter contained in this secretion; partly on account of the great variations in the amount of fluid eliminated

* Vertical section of Skin of Finger —A, Epidermis, the surface of which shows hollow depressions, *a a*, between the papillary eminences, *b*, and the openings of the perspiratory ducts, *s;* at *m* is seen the deeper layer of the epidermis, or Stratum Malpighii,—B, Cutis Vera, in which are imbedded the perspiratory glands, *d*, with their ducts, *e*, and also aggregations of fat-cells, *f;* at *g* is seen an arterial twig supplying the vascular papillæ, *p;* and at *t* one of the tactile papillæ with its nerve.

by the Sudoriparous glands, which are governed by the temperature of the skin; and partly because the secretion can scarcely be collected for analysis, free from the sebaceous and other matters which accumulate on the surface of the skin. According to Anselmino, the proportion of solid matter varies from ½ to 1½ per cent.; and it consists in part of lactic acid, to which the acid reaction and sour smell of the secretion are due; in part of a protein-compound, which is probably furnished by the epithelium-cells that line the tubes; and in part of saline matters, directly proceeding from the serum of the blood. Urea has been recently detected in the perspiration of the inhabitants of warm climates.

745. The amount of fluid excreted from the Skin is almost entirely dependent upon the *temperature* of the surrounding medium; being increased with its rise, and diminished with its fall. The *object* of this variation is very evident; being the regulation of the temperature of the body. When the surface is exposed to a high degree of external heat, the increased amount of fluid set-free from the perspiratory glands becomes the means of keeping down its own temperature; for this fluid is then carried-off in a state of vapour, as fast as it is set-free; and in its change of form, it withdraws a large quantity of caloric from the surface. But if the hot atmosphere be already loaded with vapour, this cooling power cannot be exerted; the temperature of the body is raised; and death supervenes, if the experiment be long continued. The *cause* of the increased secretion is probably to be looked-for in the increased determination of blood to the skin, which takes-place under the stimulus of heat.—The entire loss by Exhalation from the lungs and skin, during the twenty-four hours, seems to average a little above 2 lbs. In a warm dry atmosphere, however, it has been found to rise to as much as 5 lbs.; whilst in a cold damp one, it may be lowered to 1⅞ lb. Of this quantity, the pulmonary exhalation is usually somewhat less than one-third, and the cutaneous somewhat more than two-thirds; but when the quantity of fluid lost is unusually great, the increase must be chiefly in the Cutaneous exhalation; since, as already pointed out (§ 701), the amount of exhalation from the lungs is not influenced by the external temperature, but only by the degree in which the surrounding air is previously saturated with moisture.

746. The variations in the amount of fluid set-free by Cutaneous and Pulmonary Exhalation, are counterbalanced by the regulating action of the Kidney (§ 729); which allows a larger proportion of water to be strained-off in a liquid state from the blood-vessels, as the Exhalation is less,—and *vice versâ*. The Cutaneous and Urinary excretions seem to be vicarious, not merely in regard to the amount of fluid which they carry-off from the blood, but also in respect to the solid matter which they eliminate from it. It appears that at least 100 grains of effete azotized matter are daily thrown

off from the Skin; and any cause which checks this excretion, must increase the labour of the Kidneys, or produce an accumulation of noxious matter in the blood. Hence attention to the functions of the skin, at all times a matter of great importance, is peculiarly required in the treatment of Urinary diseases; and it will be often found that no means is so useful in removing the lithic acid deposit, as copious ablution and friction of the skin, combined with exercise. When the exhalant action of the Skin is completely checked by the application of an impermeable varnish, the effect is not (as might be anticipated) an elevation of the temperature of the body; on the contrary it is lowered, in consequence, as it would appear, of the interruption to the aeration of the blood through the skin, which is a function of such importance in the lower animals (§ 671), and of no trifling account in Man; and in a short time, a fatal result ensues. A partial suppression by the same means gives rise to febrile symptoms, and to Albuminuria, or escape of the albuminous part of the liquor sanguinis into the urinary tubes, in consequence (it would appear) of the increased determination which then takes-place towards the Kidneys. These facts are interesting, as throwing light upon the febrile disturbance that accompanies those cutaneous diseases which affect the whole surface of the skin at once, and interfere with its functions; and as partly accounting also for the Albuminuria, which frequently manifests itself during their progress, especially in Scarlatina. The peculiar poison of the last-named disease, however, seems to have a special action on the tubuli uriniferi, occasioning a desquamation of their epithelium, as it does of the cutaneous epidermis.

747. The Skin is likewise furnished with numerous *Sebaceous* glands, which are distributed more or less closely over the greater part of the surface of the body; being most abundant on parts most thickly covered with hair, and least numerous where the hair is scanty; whilst they are altogether absent in parts which have no hair, such as the palms of the hands and soles of the feet, on which the Perspiratory glands are most numerous. They differ greatly in size and in degree of complexity; sometimes consisting of short straight follicles; sometimes closely resembling the Sudoriparous glandulæ, the tubes, however, being usually straighter and wider; and being sometimes much more complex in structure, consisting of a number of distinct sacculi clustered round the extremity of a common duct into which they open, and forming little arborescent masses about the size of millet seeds. In the hairy parts of the skin, we usually find a pair of Sebaceous follicles opening into the passage through which every hair ascends. In some situations they acquire still greater complexity. Thus the Meibomian glandulæ, which are found at the edges of the eyelids, and which secrete an unctuous matter for their lubrication, are long sacculi branching out at the sides (Fig. 118); and the glandulæ of the ear-passage,

which secrete its cerumen or waxy matter, and which belong to the general Sebaceous system, are formed of long tubes, highly contorted, and copiously supplied with blood-vessels. The purpose of the sebaceous secretion is evidently to prevent the skin from being dried and cracked by the influence of the sun and air. It is much more abundant in those races of mankind which are formed to exist in warm climates, than in the races that naturally inhabit cold countries; and the former are accustomed to aid its preservative power, by lubricating their skin with vegetable oils of various kinds; which process they find to be of use, in protecting it from the scorching influence of the solar rays.—The Sebaceous follicles, especially in the face, are frequently the residence of a curious parasite, the *Demodex folliculorum*, which is stated by Mr. Erasmus Wilson to be present in great numbers in the skin of almost all inhabitants of large towns; the activity of their cutaneous glandular system being much checked, by the want of free exposure to pure air and by inert habits of life.

748. To what extent the Sebaceous secretion can be regarded as destined to free the Blood from deleterious matters, it may not, perhaps, be very easy to say; but with regard to the functions of the Skin taken altogether as a channel for the elimination of morbific matters from the blood, it is probable that they have been much under-rated; and that much more use might be made of it in the treatment of diseases,—especially of such as depend upon the presence of some morbific matter in the circulating current,—than is commonly thought advisable. We see that Nature frequently uses it for this purpose; a copious perspiration being often the turning-point or 'crisis' of febrile diseases, removing the cause of the malady from the blood, and allowing the restorative powers free play. Again, certain forms of Rheumatism are characterised by copious acid perspirations; and instead of endeavouring to check these, we should rather encourage them, as the best means of freeing the blood from its undue accumulation of lactic acid. And it is recorded that in the 'sweating sickness,' which spread throughout Europe in the 16th century, no remedies seemed of any avail but diaphoretics; which, aiding the powers of nature, concurred with them to purify the blood of its morbific matter. The hot-air bath, in some cases, and the wet sheet (which, as used by the Hydropathists, is one of the most powerful of all diaphoretics), will be probably employed more extensively as therapeutic agents, in proportion as the importance of acting on the Skin, as an extensive collection of glandulæ, comes to be better understood. The absurdity of the 'Hydropathic' treatment consists in its indiscriminate application to a great variety of diseases; no person who has watched its operation, can deny that it is a remedy of a most powerful kind; and if its agency be fairly tested, there is strong reason to believe, that it will be found to be the most valuable

curative means we possess for various specific diseases, which depend upon the presence of a definite *materies morbi* in the blood, especially Gout and Chronic Rheumatism; as well as for that depressed state of the general system, which results from the 'wear and tear' of the bodily and mental powers.

749. The Mucous surface of the Alimentary Canal is furnished, like the skin, with a vast number of glandulæ, varying in complexity from the simple follicle, to a mass consisting of numerous lobules opening into a common excretory duct. The functions of these, as already pointed-out, are equally various. The simple follicles appear destined, for the most part, to secrete the protective mucus which intervenes between the membranous wall and the substances contained in the canal, and which serves to protect the former from the irritating action of the latter. The more complex follicles of the Stomach elaborate the Gastric fluid, which is the prime agent in the digestive process (§ 469). The still more elaborate glandulæ of Brunner, situated in the walls of the duodenum, also seem to furnish a product which is concerned in the digestive operation (§ 481). But there is strong reason to believe, that the function of the glandulæ which beset the walls of the lower part of the intestinal canal, is purely excretory; and that they are destined to eliminate putrescent matters from the blood, and to convey them, by the readiest channel, completely out of the body. That the putrescent elements of the fæces are not immediately derived from the food taken-in, so much as from an excretory process, appears from this consideration;—that fæcal matter is still discharged, even in considerable quantities, long after the intestinal tube has been completely emptied of its alimentary contents. We see this in the course of many diseases, when food is not taken for many days, during which time the bowels are completely emptied of their previous contents by repeated evacuations; and whatever then passes must be derived either from the intestinal walls themselves, or from the glands that discharge their contents into the cavity. Sometimes a copious flux of putrescent matter continues to take place spontaneously; whilst it is often produced by the agency of purgative medicine. The 'colliquative diarrhœa,' which frequently comes-on at the close of exhausting diseases, and which usually precedes death by starvation, appears to depend, not so much upon a disordered state of the intestinal glandulæ, as upon the general disintegration of the solids of the body, which calls them into extraordinary activity for the purpose of separating the decomposing matter.

750. Thus we perceive that we have here, also, to watch for the indications of Nature; and that this extensive system of intestinal glandulæ, being the principal channel for the elimination of putrescent matters from the blood, should be especially attended-to, when there is reason to think that such matters are present in too

large an amount. Hence, when diarrhœa is already existing, we may often do more good by allowing it to take its course, or even by increasing it by the agency of mild purgative medicines, than by attempting to check it, and thus causing the retention of the morbid matter in the circulating current. But, on the other hand, it is necessary to bear in mind the extreme irritability of the intestinal mucous membrane; and carefully to avoid exciting it when it is already in excess, or when there is danger that it will supervene,—as in that form of Fever, in which there is a peculiar liability to inflammation and ulceration of the walls of the alimentary canal and of their contained glandules.

5. *General Summary of the Excreting Processes.*

751. We have now passed in review the various processes, by which the products of the disintegration of the animal tissues are carried-off; and we have seen that the necessity for their removal is much more urgent than for the replacement of the substances from which they proceeded. A cold-blooded animal may subsist for some weeks, or even months, without a fresh supply of food, the waste of its tissues being so small, if it remain in a state of rest, as to be quite compatible with the continuance of its life; and a warm-blooded animal may live for many days or even weeks, provided that it has in its body a store of fat sufficient to keep-up its heat by the combustive process. But in either case, if the exhalation of carbonic acid by the lungs, the elimination of biliary matter by the liver, the separation of urea or uric acid by the kidneys, or the withdrawal of putrescent matter by the intestinal glandulæ, be completely checked, a fatal result speedily ensues;—more speedily in warm-blooded animals, than in those which cannot sustain a high independent temperature, on account of the greater proneness to decomposition in the bodies of the former, than in those of the latter;—and more speedily in the latter, when their bodies are kept at an elevated temperature by the warmth of the surrounding medium, than when the degree of heat is so low, that there is little proneness to spontaneous change in the substance of their bodies.

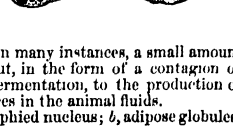
752. It may be taken as a general principle, in regard to the Excreting processes (including Respiration), that they have a three-fold purpose;—in the first place, to carry-off the *normal* results of the waste or disintegration of the solid tissues, and of the decomposition of the fluids;—in the second place, to draw-off the superfluous alimentary matter, which, though received into the circulating current, is not converted into solid tissue, in consequence of the want of demand for it;—and in the third place, to carry-off the *abnormal* products, which occasionally result from irregular or morbid changes in the system. Thus by the Lungs are excreted a large amount of carbon, and some hydrogen, resulting from the

disintegration of the tissues, especially the nervous and muscular; the same elements, in animals that take-in a large proportion of farinaceous or oleaginous aliment, may be derived immediately from the food, without any previous conversion into solid tissue; and there can be little doubt that the respiratory function is also an important means of purifying the blood from various deleterious matters, either introduced from without (such as alcohol and other narcotic poisons), or generated within the body (such as the poison of fever*). And it is important to bear this last circumstance in mind; since it enables us to understand how, if *time* be given, the system *frees itself* from such noxious substances; and points-out the duty of the medical attendant to be rather that of supporting the powers of the body by judiciously-devised means, and of aiding the elimination of the morbid matter through the lungs and skin by a copious supply of pure air, than of interfering more actively to promote that which Nature is already effecting in the most advantageous manner.

753. In like manner, the Liver is charged with the separation of *hydrocarbon* in a fluid form; for which a supply of oxygen is not requisite. This product is partly derived from the waste of the system; but the arrangement of the biliary vessels leads to the belief, that part of it may be at once derived from crude matter taken-up by the mesenteric veins, and eliminated from them by the hepatic cells without ever passing into the general circulation. And various facts seem to indicate that the Liver is also destined to remove from the blood extraneous substances which are noxious to it. Thus, in cases where death has resulted from the prolonged introduction of the salts of Copper into the system, a considerable amount of that metal has been obtained from the substance of the gland.

754. It has been already pointed-out (§ 725), that in those tribes of animals whose respiration is feeble, a considerable part of the mass of the liver is composed of fatty matter; and this condition may be induced, as a state of disease, in warm-blooded energetically respiring Birds and Mammals, by impediments to the due performance of the respiratory process. This is remarkably shown in the treatment of the geese which are to furnish the celebrated Strasburg *pâtés*. The unfortunate bird is closely confined at a high tempera-

Fig. 142.†



* There is strong reason to believe that, in many instances, a small amount of poisonous matter introduced from without, in the form of a contagion or miasm, may lead, by a process resembling fermentation, to the production of a large quantity of similar noxious substances in the animal fluids.

† Hepatic Cells gorged with Fat:—*a*, atrophied nucleus; *b*, adipose globules.

ture, so that the respiration is reduced to its minimum amount by the combined effects of warmth and muscular inaction; and it is then crammed with maize, which contains a large amount of oily matter. The consequence is, that its liver soon enlarges, and becomes unusually fatty; its cells being gorged with oil-globules, instead of each containing no more than one or two: and it is then ready for the epicureans who set so high a value on the *pâté de foie gras*. A similar diseased condition of the liver frequently presents itself in Man, in connexion with chronic disorders of the respiratory organs, which diminish the amount of hydrocarbon eliminated through their agency; this 'fatty liver' is peculiarly common in the advanced stages of Phthisis. It may arise, however, from a local disorder of nutrition, such as that which produces the *fatty degeneration* of other organs. But this fatty degeneration, which usually commences with an increase in the proportion of fat in the blood, may itself be attributed to a disproportion between the amount of that substance in the circulating current, and the rate of the oxygenating process by which it is eliminated. Generally speaking, it depends upon some want of activity in the general habits, which keeps-down the respiration to too low a standard; and it is a very common disorder among elderly persons, whose energy has not been sustained by adequate bodily exercise. But another most frequent cause, is the habitual presence of Alcohol in the circulating current; for this substance may be said to rob the blood of its oxygen, taking to itself that which would otherwise be appropriated to the elimination of the effete matters of the system; and as the blood of drunkards contains an enormous proportion of fatty matter, it may be fairly presumed that a corresponding retardation will occur in the normal combustion of fat, even in the case of those who make use of the same substance to a less excessive amount.

755. With regard to the Kidneys, it has been already pointed out that they are the special emunctories of the *azotized* products of the decomposition of the tissues; and that they serve also to convey-away the overplus of such earthy and alkaline salts as are readily soluble. Moreover, it has been shown that the surplus protein-compounds, which are not required for the nutrition of the system, must be excreted by their agency, after having been metamorphosed into urea. And we have now to notice that other matters of an injurious character, whether introduced from without, or generated within the system, are drawn-off by the same channel. Thus the saline compounds taken-up by the absorbent process (§ 492), are for the most part set-free through these organs; especially when their properties are such as to excite the action of the kidneys in a peculiar degree. Thus, Prussiate of Potash has been detected in the urine, within one minute after it had been introduced into the stomach. It has been sometimes noticed that Iodide of Potassium, when administered as a medicine, is retained within the body for

some days, producing extensive cutaneous eruptions, or some other unusual consequence; and that it then suddenly begins to pass-off by the kidneys, and is excreted in very large quantities. Further, it has been shown that poisonous substances (such as arsenious acid), introduced into the system in small but frequently-repeated doses, may be carried out of the body with such rapidity as to be prevented from exerting their injurious effects, provided that diuretics be administered at the same time. The effect of the inhalation of the vapour of turpentine, even in a very diluted state, in speedily imparting to the urine the odour of violets, is an evidence that not merely the actual substances imbibed, but new and peculiar compounds to which they give-rise, are thus eliminated by the Kidneys.

756. The most singular variations in the excretory function of the Kidneys are seen, however, when the Urine is charged with substances which are not only foreign to it, but are altogether foreign to the healthy body. The most remarkable instance of this presents itself in Diabetes, in which a large quantity of Sugar is formed, either directly from the food, or by the disintegration of the solid tissues; and in which this compound is eliminated by the Kidneys, imparting to the urine a saccharine taste. And another example of the same general fact is seen in the 'oxalic diathesis,' in which an unusual arrangement of the elements that usually form urea or uric acid, gives-rise to a new and peculiar compound, oxalate of ammonia; and this being drawn-off by the kidneys, and being decomposed by the calcareous matter present in the urine, occasions a deposit of oxalate of lime.—In the treatment of such diseases, our attention must be given, not so much to the secreting organ, as to the condition of the system at large, of which the character of the secreted product is the indication or exponent.

757. To what has already been stated in regard to the exhalant functions of the Lungs and Skin, it may be added that many states of disease are marked by an unusual odour emitted from the body; and there can be little doubt that the peculiar odorous matter is pre-formed in the blood, since we know that the ordinary scent of any species (whether Man, Dog, Horse, Goat, &c.) may be set-free from the blood of that species, by the addition of sulphuric acid. The existence of such odours, therefore, is not to be attributed to disordered function in the excreting organs; but to the formation of morbid products in the interior of the body, which these organs do their best to remove. The fœtid breath which frequently accompanies an attack of indigestion, is another instance of the power of the lungs to eliminate, not merely carbonic acid, but other products of those changes in composition, which the food undergoes when introduced into the system.

758. The same remarks apply, and with yet greater force, to the Intestinal glandulæ; whose function it is, not merely to remove the

putrescent matter ordinarily formed by the disintegration of the tissues, or by the decomposition of unassimilated food, but also to draw-off the still more offensive products of such changes as take place in disease. Thus there are conditions of the system, in which, without any well-marked disorder, the fæces emit a peculiarly fœtid odour; and with these is almost always associated a depressed state of mind. Now it can scarcely be doubted, that the real fault is here rather in the early part of the nutritive operations, than in the excretory function; and that the fœtor of the contents of the intestine depends upon the undue formation of putrescent matter in the system, which, by tainting the blood, causes its action upon the brain to become unhealthy. The object of the physician will be here to eliminate the morbid product, by the moderate use of purgatives; and so to regulate the diet and regimen, as to correct the tendency to its formation.—An excessive fœtor in the evacuations, as well as in the exhalations from the skin and lungs, is peculiarly characteristic of those very severe forms of typhus (now, happily, of comparatively rare occurrence), which are termed *putrid fevers*. Here the whole of the solids and fluids of the body appear to have an unusual tendency to decomposition, in consequence of the introduction of some morbid agent which acts as a *ferment;* and the system attempts to free itself from the products of that decomposition, by the various organs of excretion, particularly the Skin and Intestinal surface.

759. It is of great importance that the Student should form clear conceptions on this subject; and that he should not (as too often happens), by directing his remedies to the mere symptoms or results of a disease, act in precise opposition to the natural tendency of the system to free itself from some unusual noxious matter, through those channels which are ordinarily destined to carry-off only the regular products of its disintegration.

CHAPTER X.

OF THE DEVELOPMENT OF HEAT, LIGHT, AND ELECTRICITY, IN THE ANIMAL BODY.

760. It has been shown, in an earlier part of this volume (CHAP. II.), that *all* Vital actions require a certain amount of *Heat* for their performance; and that there is a great variety amongst the different classes of Animals, both in regard to the degree of Heat which is most favourable to the several processes of their economy, and in regard to their own power of sustaining it, inde-

pendently of oscillations in the temperature of the surrounding medium. As a general rule, the Invertebrated animals are *cold-blooded;* that is, they have little or no power of sustaining an independent temperature. The degree of energy of their vital actions entirely depends, therefore, upon the warmth they receive from the air or water they inhabit; they have no power of resisting the depressing influence of cold; and they are generally so organized as to pass into a state of complete inaction or torpidity, when the temperature sinks below a certain point, after gradually becoming more and more inert with every diminution in the heat of their bodies. The same is true, also, of most Fishes and Reptiles: but the animals of the former class, from the more equable temperature of the medium they inhabit, are not so liable to be reduced to inaction as the latter; being usually so organized as to retain their activity so long as the water around them continues liquid; and being actually imbedded in a frozen state, when the water around them is converted into ice, without the loss of their vitality. There are certain Fishes, however,—such as the Thunny, Sword-fish, and other large species of the Mackerel tribe,—which are able to sustain a temperature considerably above that of the sea they inhabit; thus in the Bonito, the heat of the body has been found to be 99°, when the temperature of the surrounding sea was but 80½°. It is not probable, however, that the temperature of the body would be kept-up to the same standard, if that of the sea should be considerably lowered; but it would probably remain at from 18° to 20° above the latter. And in like manner, it has been noticed that many of the more active Reptiles possess the power of sustaining the temperature of their bodies at 10° or 15° above that of the surrounding air.

761. The classes of animals which are especially endowed with the power of producing and maintaining heat, are Insects, Birds, and Mammalia. The remarkable variations which present themselves in the temperature of the first of these classes, and the connection of these variations with the condition of the animals in regard to activity or repose, have already been sufficiently noticed (§ 123).—The temperature of Birds is higher than that of any other class of animals; varying from 100° to 111° or 112°. The lowest degree is found in some of the aquatic species, as the Gull, and in those which principally live on the ground, as the Fowl tribe; and the highest in the birds of most active flight, as the Swallow. The temperature of the Mammalia seems to range from about 96° to 104°; that of Man has been observed as low as 96½°, and as high as 102°, the average being probably 100°. The variations are dependent in part upon the temperature of the external air; but are influenced also by the general condition of the body as to repose or activity, the period of the day, the time that has elapsed since a meal, &c. A somewhat larger amount of caloric is generated

during the day, than in the night; and the body is usually warmer by a degree or two, at noon, than at midnight. There is also a slight increase during the digestion of a meal; and exercise is a powerful means of raising the temperature.—The range of temperature is much greater in disease; thus the thermometer has been seen to rise to 106° in Scarlatina and Typhus, and to 110¾° in Tetanus; whilst it has fallen to 82° in Spasmodic Asthma, and to 77° in Cyanosis and Asiatic Cholera. It is a very remarkable fact, that the heat of the body sometimes increases after death, so as not merely to reach the natural standard where there has been previous depression (as in Cholera), but even to rise considerably above it; an elevation as high as 112° having been observed some hours after death from Yellow Fever.

762. In searching for the conditions on which this production of heat within the Animal body is dependent, it is very important to bear in mind that a similar generation of Caloric may be observed in the Vegetable kingdom. It appears from the most recent and exact experiments, that all *living* Plants are somewhat warmer than similar *dead* plants exposed to the same atmosphere; and that the elevation is the greatest in the leaves and young stems, in which the most active vital changes are taking place. But the most decided production of heat occurs in the *flowering* of certain Plants, such as the Arum, which have large fleshy receptacles whereon a great number of blossoms are crowded; thus a thermometer placed in the centre of five spadixes of the *Arum cordifolium* has been seen to rise to 111°, and one placed in the midst of twelve spadixes has risen to 121°, whilst the temperature of the surrounding air was only 66°. In the *germination* of seeds, also, a great elevation of temperature occurs, which is rendered most evident by bringing together a number of seeds, as in the process of *malting*, so that the caloric is not dissipated as fast as it is generated; the thermometer, placed in the midst of a mass of seeds in active germination, has been seen to rise to 110°.

763. Thus it is evident that the chemical changes which are involved in the operations of Nutrition, are capable of setting-free a large amount of heat; which, although ordinarily dissipated from the vegetating surface too speedily to manifest itself, becomes sensible enough when this rapid loss is checked. If we further examine into the nature of the chemical changes which appear most concerned in this elevation of temperature, we find that they uniformly consist in the combination of the carbon of the plant with the oxygen of the atmosphere; so that a large quantity of carbonic acid is formed and set-free, precisely in the manner of the Respiration of Animals. This process is so slowly performed, in the ordinary growth of Plants, that it is concealed (as it were) by the converse change,—the *fixation* of carbon from the carbonic acid of the atmosphere under the influence of light (§ 83).

But it takes-place with extraordinary energy during flowering and germination; a large quantity of carbon being set-free, by union with the oxygen of the air; and the starchy matter of the receptacle, or of the seed, being converted into sugar. Now it has been ascertained by careful experiments, that the amount of heat generated is in close relation with the amount of carbonic acid evolved; and that, if the formation of the latter be prevented, by placing the flower or the seed in nitrogen or hydrogen, no elevation of temperature takes-place; whilst, if the process be stimulated by pure oxygen, so that a larger proportion of carbonic acid is evolved, the elevation of temperature is more rapid and considerable than usual.

764. Upon examining into the conditions under which Caloric is generated in the Animal body, we find them essentially the same. Wherever the temperature of the body is maintained at a regular standard, so as to be independent of variations in the warmth of the surrounding medium, we find a provision for exposing the blood most freely to the influence of oxygen, and for extricating its carbonic acid; thus in Birds and Mammals, the blood is distributed, in a minute capillary network, on the walls of the pulmonary air-cells, the gaseous contents of which are continually renewed; and in Insects, the air is carried into every part of the body by the ramifying tracheæ. We find a constant proportion between the amount of heat evolved and that of carbonic acid generated; this is peculiarly evident in Insects, whose respiration and calorification vary so remarkably (§ 123); but it is also proved by comparing the amount of carbonic acid evolved by warm-blooded animals, when the external temperature is low, and when more heat must be generated to keep the temperature of their bodies up to its proper standard, with that evolved by the same animals in a warmer atmosphere, when the generation of animal heat takes-place at a diminished rate (§ 691).

765. The sources of the Carbonic Acid thrown-off by the lungs, have been already pointed-out (CHAP. VIII.): it is partly derived from the metamorphosis of the tissues; but partly, in all but purely carnivorous animals, more directly from the non-azotized portion of the food. The precise mode in which the Carbon thus supplied is united with the oxygen derived from the atmosphere, is not yet known; but it is certain that, in whatever manner the combination may take place, a certain measure of caloric *must* be generated. It appears, however, from various experiments, that the whole quantity of caloric generated by an animal in a given time, is *greater* than that which would be evolved by the combustion of the carbon included in the carbonic acid that is evolved during the same time. Hence it is evident that *other* chemical processes occurring within the body are concerned in the maintenance of the temperature; and it is not difficult to point to some of these. It is certain,

in the first place, that some of the Hydrogen of the food may be 'burned off' by union with the oxygen of the atmosphere, so as to form part of the water which is exhaled from the lungs. Again, the Sulphur and Phosphorus of the food are converted, by oxygenation, into sulphuric and phosphoric acids; in which process heat must be generated. In the composition of urea, moreover, oxygen is present in much larger proportion, than it is in the protein-compounds by the metamorphosis of which it is formed; so that in *its* production too, caloric will be generated. In fact it may be stated as a general truth, that the whole excess of the oxygen absorbed, over that which is contained in the carbonic acid exhaled (§ 689), must be applied to purposes in the laboratory of the system, in which caloric will be disengaged. Still, the amount of Carbonic Acid exhaled must always be the measure of the chemical processes by which heat is generated in the body; because it is itself the result of the chief of these processes (the union of carbon and oxygen), and because the surplus amount of oxygen which is absorbed, and which is applied to other purposes, is closely related to it.

766. The power of maintaining a high independent temperature, is usually much less in *young* warm-blooded animals than in adults. There are considerable variations in this respect, however, amongst different species; for where the young animal is born in such an advanced condition as to be thenceforth almost independent of parental assistance, it is capable of maintaining its own temperature; but where it is born in such a state as to require to be supplied with food by the parent for some time, it is also more or less dependent upon the warmth imparted to it from the parental body. This is peculiarly the case with the young of the Human species, which is longer dependent upon parental aid than is that of any other animal. In the case of children born very prematurely, the careful sustenance of their heat is one of the points most to be attended-to in rearing them; and even the most vigorous infants, born at the full time, are far from being able to keep-up their proper standard without assistance, if exposed to a cool atmosphere. It has been ascertained that, during the first month of infant life, the mortality in winter is nearly double that of summer, being as 139 in January to 78 in July; and this striking difference cannot be attributed to any other cause than the injurious influence of external cold, which the calorifying powers of the infant do not enable it to resist. As age advances, the power of generating heat increases, and the body becomes much more independent of external vicissitudes; so that, in adult life, the winter mortality is to that of summer only as 105 to 91, or less than one-sixth more. In advanced age, the calorifying power again diminishes; and this we should anticipate from the general torpor of the nutritive operations in old persons. Between 50 and 65 years of age, the relative winter

and summer mortality are nearly as in the first month of infancy; and at 90 years, the average mortality of winter is much more than twice that of summer, being as 1·58 to 64.

767. It appears that there is a difference in calorifying power, not merely at different ages, but at different seasons; the amount of heat generated in summer not being sufficient, in many animals, to prevent the body from being cooled-down by prolonged exposure to a temperature which is natural to them in winter. To what extent this is the case with Man, it is difficult to say. His constitution is distinguished by its power of adapting itself to circumstances; and he can live under extremes of temperature more wide than those which most other animals can endure (§ 113). Whether in the torrid zone or in the arctic regions, he can maintain his healthy condition under favourable circumstances; his natural appetite leading him, in each case, to the use of that kind and amount of food which is best suited to the wants of his system. But the longer he has been habituated to a very warm or a very cold climate, the more difficult he at first finds it to live comfortably in one of an opposite character; as his constitution, having become adapted to one particular set of circumstances, requires *time* to accommodate itself to an opposite one.

768. The means by which the heat of the body is prevented from rising *above* its normal standard, even in the midst of a very high temperature in the surrounding air, are of the most simple character. The excreting action of the skin is directly stimulated by the application of warmth to the surface; and the fluid which is poured-forth, being immediately vaporized, converts a large quantity of sensible caloric into latent, and thus keeps-down the temperature of the skin. By this provision, the body may be exposed with impunity to *dry* air of 600° or more, so long as the supply of fluid is maintained. But it cannot long sustain exposure to air saturated with vapour, even though this be not many degrees hotter than the body; because the cooling act of evaporation from the skin cannot then be carried-on.

769. The evolution of *Light* is a very interesting phenomenon, chiefly witnessed among the lower animals, and usually supposed not to occur in any class above Fishes. It is particularly remarkable among the Radiata and inferior Mollusca. A large proportion of the *Acalephæ*, or Jelly-fish tribe, possess the property of luminousness in a greater or less degree; and it is to small animals of this class, which sometimes multiply to an amazing extent, that the beautiful phenomenon of *phosphorescence of the sea* is chiefly due. In the midst of the soft diffused light thus occasioned, brilliant stars, ribands, and globes of fire are frequently seen; these appearances being due to the luminosity of the larger species of the same tribe, or to that of other marine animals.—Some examples of luminosity which are most remarkable as regards the brilliancy of

the light emitted, occur in the class of Insects. Here the emission is confined to one portion of the body, or to two or more isolated spots, instead of being diffused over a larger surface; and it is proportionally increased in intensity.—The phenomenon of Animal Luminousness appears usually attributable to the formation of a peculiar secretion, which, in many instances, continues to shine after removal from the animal, so long as it is exposed to the influence of oxygen: and there is every reason to believe that it undergoes a slow process of combustion, analogous to that which takes place when phosphorus is exposed to the air. There is a special provision, in Insects, for conveying a large supply of air through the peculiar substance which is deposited beneath the luminous spots; and the power which Glow-worms, Fire-flies, &c., possess, of suddenly extinguishing their light, and as suddenly renewing it, seems to depend upon their control over the air-aperture or spiracle by which air is admitted, the stoppage of the supply of air causing the immediate cessation of the luminousness, and its re-admission occasioning a renewal of the process on which it depends.—It is probable, however, that in certain cases, the luminosity is rather of an electrical character. There are several of the smaller Annelida or marine Worms, which are brilliantly luminous when irritated; the luminosity having the character, however, of a succession of scintillations, rather than of a steady glow. It appears from the experiments of M. Quatrefages, that this peculiar luminosity is the especial attribute of the muscular system; and that it is produced with every act of muscular contraction in these animals.

770. No such luminosity is commonly manifested in any of the higher Vertebrata, or in Man; although luminous emanations from dead animal matter are of no unfrequent occurrence. There are well-authenticated cases, however, in which the phenomenon has presented itself in the *living* Human subject.* But in most of these cases, the individuals exhibiting the luminosity had suffered from consumption, or some other wasting disease, and were near the close of their lives at the time; so that it is probable that a decomposition of the tissues was actually in progress, analogous to that which, when it occurs after death, imparts luminosity to the decaying body. One instance is recorded, in which a large cancerous sore of the breast emitted light enough to enable the hands on a watch-dial to be distinctly seen when it was held within a few inches of the ulcer; here, too, decomposition was obviously going on, and the phosphorescent matter produced by it was exposed to the oxygenating action of the atmosphere.

771. Slight manifestations of free *Electricity*, or, in other words, disturbances of Electric equilibrium, are very frequent in living

* See an account of several cases of the Evolution of Light in the Living Human Subject, by Sir Henry Marsh, M.D., M.R.I.A., &c.

animals; and they are readily accounted-for, when we bear in mind that every chemical change is attended with some alteration in the electric state of the bodies concerned, and when we consider the number and variety of such changes in the living animal body. When slight, however, they can only be detected by refined means of observation; and it is only when they are considerable, that they attract notice. The most remarkable examples of the evolution of free Electricity in Animals, are to be found in certain species of the class of Fishes; the best-known of which are the *Torpedo* or Electric Ray, and the *Gymnotus* or Electric Eel. These possess organs in which Electricity may be generated and accumulated in large quantities, and from which it may be discharged at will. The shock of a large and vigorous Gymnotus is sufficiently powerful to kill small animals, and to paralyse large ones, such as men and horses: that of the Torpedo is less severe, but it is sufficient to benumb the hand that touches it.

772. The electric organs of the Torpedo (which fish, from being found on European shores, has been the most studied) are of flattened shape, and occupy the front and sides of the body; forming two large masses, which extend backwards and outwards from each side of the head. They are composed of two layers of membrane separated by a considerable space; and this space is divided by vertical partitions into hexagonal cells like those of a honeycomb, the ends of which are directed towards the two surfaces of the body. These cells, which are filled with a whitish soft pulp, somewhat resembling the substance of the brain, but containing more water, are again subdivided horizontally by membranous partitions; and all these partitions are profusely supplied with blood-vessels and nerves.—The electrical organs of the Gymnotus are essentially the same in structure; but they differ in shape, in accordance with the conformation of the animal.—In these, as in the other Electrical fishes, the electric organs are supplied with nerves of very great size, larger than any others in the same animals, and larger than any nerves in other animals of similar bulk. These nerves arise from a peculiar ganglionic enlargement of the Medulla Oblongata, termed the *electric lobe*, and seem chiefly analogous to the pneumogastrics of other animals.

773. The following conditions appear to be essential to the manifestation of the Electric powers of these animals. Two parts of the body must be touched at the same time; and these two must be in different electrical states. The most energetic discharge is procured from the Torpedo, by touching its back and belly simultaneously; the electricity of the back being positive, and that of the belly negative. When two parts of the same surface, at equal distances from the electric organ, are touched, no effect is produced, as they are equally charged with the same electricity; but if one point be further from it than the other, a discharge occurs, the intensity of

which is proportioned to the difference in the distance of the points from the electric organ. However much a Torpedo is irritated, no discharge can take-place through a single point; but the fish makes an effort to bring the border of the other surface into contact with the offending body, through which a shock is then transmitted. This, indeed, is probably the usual way in which the discharge is effected.—The identity of *animal* with *common* Electricity is proved, not merely by the similarity of the effects upon the feelings produced by the shock of both; but also by the fact that a spark may be obtained, and chemical decompositions effected, by the former, precisely as by the latter.

774. The power of the animal over the actions of its Electric organs, is dependent upon their connection with the nervous centres. If all the nerve trunks supplying the organ on one side be divided, the animal's control over that organ will be destroyed; but the power of the other may remain uninjured. If the nerves be partially divided on either or both sides, the power is retained by those portions of the organs which are still connected with the centres by the trunks that remain. Even slices of the organ entirely separated from the body except by a nervous fibre, may exhibit electrical properties. Discharges may be produced, by irritating the part of the nervous centres from which the trunks proceed, so long as the latter are entire; or by irritating the portions of the divided trunks which remain in connection with the electric organs; or even by irritating portions of the electric organs themselves, when separated from the nervous centres.—In all these respects, there is a strong analogy between the action of the nerves on the Electric organs, and their action on the Muscles. The connection of the organs specially appropriated to each of these actions with the Nervous system, the dependence of their continued action upon the integrity of this connection and upon the state of activity of the central organs, the influence of stimulation applied to the nervous centres or trunks, the results of ligature or section of the nerve, and the effects of poisonous agents, are all so remarkably analogous in the two cases, that it seems scarcely possible to doubt that the Nervous force is the agent which is instrumental in producing both sets of phenomena. Still, however, no proof whatever can be derived from this source, of the *identity* of nervous influence with any form of Electricity; since all that can be legitimately inferred from it is, that Nerve-force acting through a particular organic structure developes Electricity, in virtue of the *correlation* formerly explained (§ 396).

775. It is another interesting point of analogy between the action of Muscles and that of the Electrical organs, that the former, like the latter, is attended with electric disturbance. In any fresh vigorous muscle, there is a continual electric current from the interior to the exterior, sufficient to excite the leg of a frog to ener-

getic contraction, when its nerve is so applied to the muscle as to be subjected to its influence. The explanation of the constant direction of this current, from the interior towards the exterior of the muscle, seems to be, that the changes connected with the nutrition and disintegration of the muscular tissue go-on more energetically in its interior, than they do nearer its surface, where the proper muscular fibres are mingled with a large proportion of areolar and tendinous substance.—It was observed by Galvani that there exists in the Frog, during its whole life, a continual current of Electricity, passing from its extremities towards its head; and as no such current has been detected in any other animal, it has been termed the *courant propre*, or peculiar current, of the Frog. It bears this curious analogy to the electric discharges of Fishes; that it is *not* manifested if the connection be made between corresponding points of the opposite sides, but that it shows itself when the communication is made between points higher or lower in the body, whether on the same or on opposite sides. It has now been fully demonstrated, however, by the researches of Matteucci and Du Bois-Reymond, that this 'proper current of the frog' is but a special case of the ordinary muscular current, depending upon the peculiar arrangement of the muscular and tendinous elements in this animal. Both currents are alike influenced by agents which affect the vitality of the muscle; and it is curious that poisoning with sulphuretted hydrogen should almost immediately put an end to each, although ordinary narcotic poisons have very little influence.

776. That a change in the electrical state of muscles takes-place in the act of contraction, had been ascertained by the experiments of Matteucci; but he was unable to determine its nature with accuracy. By the very accurate experiments of Du Bois-Reymond, however, it has been demonstrated that this disturbance consists in the diminution, or even the entire suspension, of the muscular current, which is renewed again so soon as the contraction of the muscle gives-place to relaxation.—It has been further discovered by Du Bois-Reymond, that an electric current exists in Nerves, the conditions of which are in most respects similar to those of the muscular current. The investigation of its laws is of the highest scientific interest, and will probably lead in time to important practical results; but since it must be regarded as at present very incomplete, and no general conclusions having any therapeutic value can be drawn from it, an account of the facts hitherto ascertained would be rather a source of perplexity than of information to the ordinary reader.

777. Manifestations of Electricity may be produced, in most animals having a soft fur, by rubbing the surface, especially in dry weather; this is a fact sufficiently well known in regard to the domestic Cat. Some individuals of the Human race exhibit spontaneous manifestations of electricity, which are occasionally of very

remarkable power. There are persons, for instance, who scarcely ever pull-off articles of dress that have been worn next their skin, without sparks and a crackling noise being produced, especially in dry weather. This is partly due, however, to the friction of these materials with the surface and with each other. But the case of a lady has not long since been put on record, who was for many months in an electric state so different from that of surrounding bodies, that, whenever she was but slightly insulated by a carpet or other feebly-conducting medium, sparks passed between her person and any object which she approached. When she was most favourably circumstanced, four sparks per minute would pass between her finger and the brass ball of a stove, at a distance of $1\frac{1}{2}$ inch. Various experiments were tried with the view of ascertaining if the Electricity was produced by the friction of articles of dress; but no change in these seemed to modify its intensity. From the pain which accompanied the passage of the sparks, this condition was a source of much discomfort to the subject of it.

CHAPTER XI.

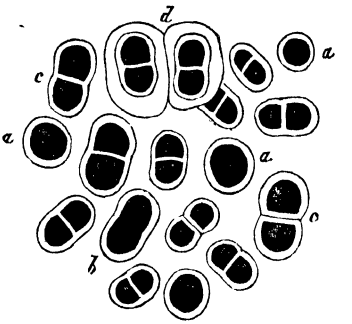
OF GENERATION AND DEVELOPMENT.

1. *General View of the Nature of the Process.*

778. There is no one of the functions of living beings that distinguishes them in a more striking and evident manner from the inert bodies which surround them, than the process of Generation. By this function, each *race* of Plants and Animals is perpetuated; whilst the *individuals* composing it successively disappear from the surface of the earth, by that death and decay which are the common lot of all. There are certain tribes in which the death of the parent is necessary for the liberation of the germs, from which a new race is to spring-up. This is the case, for example, in some of the simplest Cellular Plants; in which every cell lives for itself alone, and performs its whole series of vital operations independently of the rest. But as, in more complex organisms, we find certain cells set-apart for Absorption, others for Secretion, &c., so do we find a particular group of cells set-apart for Reproduction; and these go through a series of changes peculiar to themselves, without interfering with the general life of the structure.—It is in the Vegetable kingdom that the essential character of the Generative process can be best studied; and we shall in the first instance, therefore, inquire into the nature and import of the principal phenomena which it presents.

779. If we take as our starting-point the simple cell in which the *individuality* of the lowest Algæ seems to reside, we find that such a cell, under the influence of light and warmth, and supplied with aliment, multiplies itself to an extent that almost seems unlimited; and this by a process of duplication exactly analogous to that which has been already described (§ 211) as taking-place in Cartilage;—the chief difference being, that in the latter the fission commences in the nucleus, each half of which seems to draw around it a portion of the contents of the cell, whilst in the former the fission shows itself at once in the entire endochrome, there being no distinct nucleus (Fig. 143). Now although the effect of this opera-

Fig. 143.*

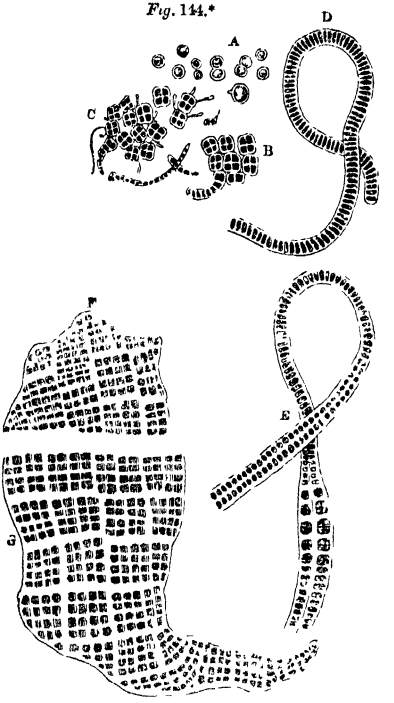


tion is to produce a great number of new cells, yet it cannot be truly considered as an act of Generation; for it is obviously analogous to that multiplication of the component cells, which takes-place as a part of every process of *development* in the most complex organisms; the only difference being, that the new cells are here in great degree independent one of another, so as to be able to maintain their existence when isolated; whilst among the higher tribes, there is so close a relation of mutual dependence between the component cells, that they cannot continue to live if separated one from another. And we shall hereafter see that the early development of the embryonic mass, even in the highest Animals, presents phenomena in all respects comparable to this multiplication of the simplest Cellular Plants by successive subdivision (§ 805); all the

* Various stages of development of *Hæmatococcus binalis*:—*a*, *a*, simple rounded cells; *b*, elongated cells, the endochrome preparing to divide; *c*, *c*, cells in which the division has taken-place; *d*, cluster of four cells formed by a repetition of the same process.

descendants of the original cell, however, here remaining in mutual apposition, and concurring to make-up what is commonly designated as a single individual; whilst in the simplest Plants, these cells, as their number is successively augmented by fission, are more and more widely separated from each other, and may disperse themselves over an extensive surface.—If, however, they should remain in connection with each other, they may form clusters, or fronds (expanded leafy surfaces), according to the direction in which the

Fig. 144.*



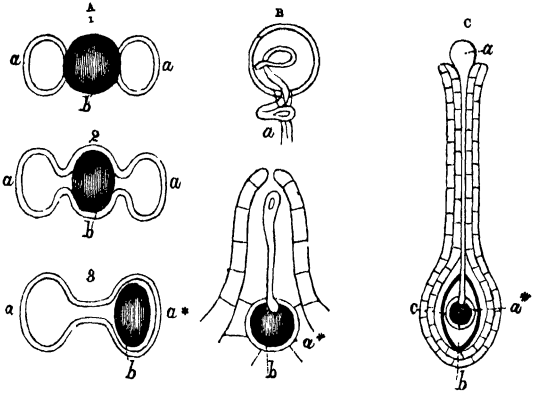
* Successive stages of development of simpler Algæ:—A, individual cells of *Protococcus viridis*; B, C, clusters formed by their multiplication; D, filament of *Schizogonium murale*; E, a similar filament, subdividing laterally, which constitutes the early form of the *Ulvaceæ*; F, G, portions of the expanded thallus of *Ulva furfuracea*, formed by the continuance of the same process of transverse subdivision.

subdivision takes place (Fig. 144); and this without the slightest departure from the original cellular type, which is preserved throughout the structure, every part being exactly similar to every other.—In these composite organisms, we usually find a provision, not merely for the extension of the original structure, but for the multiplication of individuals; which, being still referable to the general type of cell-subdivision, must be considered as a process of *development* rather than of *generation*. This consists in the emission, from the interior of certain of the cells, of broods of young cells formed in their interior; and these, in the lower aquatic plants, are very commonly furnished with cilia, by the agency of which they are dispersed through the water, beginning to develope themselves into the likeness of the organisms from which they sprang, as soon as their movement has ceased. These 'zoospores,' as they are termed, must be regarded as the representatives of the *gemmæ* or buds of higher Plants. The latter are usually developed in continuity with the stock from which they originate; but there are many instances in which they are spontaneously detached; and there are few cases in which they will not continue their existence under favourable circumstances, when artificially separated from it, as is practised in the operations of grafting, budding, &c.

780. The true Generative process, on the other hand, seems to consist, throughout the Vegetable kingdom, in the *reunion* of the contents of two cells which have been separated in the process of development and multiplication, and in the production of a *germ* as the result of this reunion, which is usually very different in its characters and properties from either of the cells whose contents have contributed to form it. This process has been observed to take place in the Vegetable kingdom, under three principal forms, which seem to be characteristic of the lowest Cryptogamia, of the higher Cryptogamia, and of the Phanerogamia, respectively.—The *first* of these presents itself in those simple Cellular Plants, in which, whether the cells remain in connection or not, their endowments are all of the same nature. At a certain time of the year (it would seem) in each species, the cells approach one another in pairs, and their endochromes (or coloured contents) are intermingled (Fig. 145, A), either by the rupture of both cells (1), or by the formation of a direct communication from the interior of one to that of the other, in which last case the union of the two endochromes may take-place either in the connecting channel (2) or in one of the pair of cells (3). Of this process, which is known as *conjugation*, the result is the formation of a peculiar cell, from which a 'new generation' is developed by the subsequent process of fission and multiplication, and which may be appropriately termed the 'primordial cell.' There is here no definite distinction of the sexes, the conjugating cells being apparently alike in their endowments: such a distinction is shadowed-forth, however, where the sporangium is

developed within one of them.—The second form of the true generative process is seen even in the higher Algæ; and although the extent of its prevalence has not yet been certainly determined, it is probably common to the Lichens, Fungi, Liverworts, Mosses, and

Fig. 145.*



Ferns. In conformity with the separation or specialization of organs which is characteristic of these Plants, we find that the Generative power is now limited to certain small parts of them, and that these produce two orders of cells, very distinct in their endowments, which may be called respectively 'sperm-cells' and 'germ-cells.' It is from the latter that the new plant originates; but this it can only do, when the fertilizing influence of the former has been conveyed to it; and the provision for this purpose is very remarkable. The 'sperm-cells,' developed within bodies termed *antheridia*, form in their interior, as their characteristic products, minute spirally-coiled filaments, usually furnished with cilia at

* Diagram representing the three principal forms of the Generative process in Plants:—A, conjugation of inferior Cryptogamia; formation of the primordial cell, *b*, by admixture of the discharged endochromes of the parent-cells, *a*, *a*; 2, production of the primordial cell, *b*, within a dilatation formed by the union of the two parent-cells; 3, production of the primordial cell, *b*, by the passage of the endochrome of cell *a* into that of cell *a*,* marking-out a sexual difference.—B, fertilization of germ in higher Cryptogamia; *a*, sperm-cell discharging its spiral filament; *a**, germ-cell, against which one of these filaments is impinging; *b*, primordial cell produced by their contact.—C, fertilization of germ in Phanerogamia; *a*, germ-cell, or pollen-grain, sending its prolonged tube down the style, until it reaches *a** the germ-cell, inclosed in the ovule, the section of whose coats is shown at *c*: from the contact of the two, is produced the germ or primordial cell, *b*.

one extremity, and bearing a very close resemblance to the spermatozoa of animals (§ 785). These, when liberated from the cells within which they were formed, possess a very active power of movement, in virtue of which they make their way to the 'germ-cells;' and when they have impinged against these, there is reason to believe that they dissolve-away, and that the product of their diffluence is absorbed into the germ-cells and mingles with the contents of the latter, the formation of a 'primordial cell' being the result of this intermixture (Fig. 145, B). Here, then, we have the distinction of sexes well marked; but both 'sperm-cells' and 'germ-cells' are usually developed in the same organism, and are alike the product of a single original germ. Throughout the Cryptogamic series, the fertilized germ appears to be thrown at once upon the world, and is dependent for its supply of food upon its own absorbing and assimilating powers; these enable it to multiply itself by fission, sometimes to a vast extent; and thus an elaborate and complex organism (such as a Tree-Fern) may be produced.—In the *third* form of the generative process, which is peculiar to Phanerogamia (or Flowering Plants), there is the same distinction between 'sperm-cells' and 'germ-cells;' but the mode in which the action of the former upon the latter is brought-about, is very different. The 'sperm-cell,' which is known as the 'pollen-grain,' and is developed in the anthers of the flower, does not here evolve self-moving filaments, but, when it falls upon the apex of the style, puts-forth long tubes, which insinuate themselves down between its loosely-connected tissue, until they reach the ovary at its base. Here they meet with the ovules, which are in reality 'germ-cells' imbedded in a mass of nutriment stored-up by the parent; and the pollen-tube, entering the micropyle or foramen of the ovule, penetrates into such close approximation to the germ-cell contained within it, that its contents find a ready passage by endosmose into the latter (Fig. 145, C). Here again, therefore, we have the same essential phenomenon,—the intermixture of the contents of the sperm-cell and of the germ-cell, as the condition for the development of the true germ. But this germ, still making its first appearance as a single cell within the ovule, is supplied with nutriment by its parent; and this not merely whilst the ovule remains in connection with the organism which evolved it, but for some time subsequently; the store laid-up around it in the seed, being the material at the expense of which its early development takes place. It is not, in fact, until its true leaves have been evolved and its root-fibres have penetrated the soil, as takes-place in the act of germination, that it becomes capable of absorbing and assimilating nutriment for itself. So soon, however, as germination has been completed, the young plant becomes independent of further assistance; and all its subsequent growth is provided-for by its own powers. In process of time, its generative apparatus is evolved;

and here, too, we find that the two sets of sexual organs are usually developed in the same organism, it being only a small proportion of Phanerogamia that are *diœcious*, *i. e.*, that have the male or staminiferous flowers, and the female or pistilline, restricted to different individuals.*

781. The history of embryonic Development in Flowering Plants, presents some interesting points of correspondence with that of the higher Animals.—The germ that is developed within the germ-cell (here designated the 'embryonic vesicle' of the ovule) as the product of the admixture of its contents with those of the sperm-cell (or pollen-grain), is itself a single cell; and the early history of its development closely resembles that which may be observed in all the inferior Plants. In the first place it subdivides into two, each of these into two others, and so on; its first *nisus* or tendency being to the production, not of the parts which are to be evolved into the stem roots, leaves, &c., of the perfect plant, but of a leaf-like expansion, which may be likened to the frond of the Cryptogamia, and of which the function is only temporary. It is by this organ, the single or double *cotyledon*, that the nourishment provided in the ovule is absorbed and prepared for the development of the young Plant; the permanent fabric of which, even at the time of the maturity of the seed, forms but a small proportion of the entire embryonic structure. In the act of germination, however, the permanent portions are developed at the expense of the temporary, the plumula and radicle absorbing the nourishment which has been elaborated by the cotyledons; and having fulfilled its transient purpose, and completed its term of life, the first leaf-like expansion withers and dies. The tissues of the young Plant are at first of the simplest possible character; but as the organs characteristic of its adult condition are one after another put-forth (always originating in peculiar groups of cells), so do we find that the spiral vessels, woody fibre, &c., characteristic of the higher organisms, gradually make their appearance.—Thus we see that even the highest Plants have to pass through conditions closely conformable to those which are permanently shown in the lower; and that the parts which are first formed are destined for only a temporary purpose, that of preparing nourishment for the evolution of more permanent structures. We shall find, in tracing the history of the development of the higher Animals, that exactly the same general fact may be observed, in even a more striking manner; the number of different stages being greater, and a yet larger proportion of the parts first formed having a merely temporary purpose, and being destined to an early decay as soon as the more permanent parts of the fabric shall have been evolved.

* For a more particular account of the recent discoveries on which the above account of the Generation of Plants is based, see the Author's "Principles of Comparative Physiology," Chap. xi. sect. 2.

782. Among many of the lower Animals, a multiplication of individuals takes-place by a process that closely resembles the *budding* of Plants; this also must be regarded, not as a proper act of Generation, but as a modification of the ordinary Nutritive process. The same may be said of the powers of reparation, which every Animal body possesses in a greater or less degree, but which are by far the most remarkable among the lower tribes; for when an entire member is renewed (as in the Star-fish), or even the whole body is regenerated from a small fragment (which is the case in many Polypes), it is by a process exactly analogous to that which is concerned in the reparation of the simplest wound in our own bodies, and which, as already explained (§ 636), is but a modification of the process that is constantly renewing, more or less rapidly, every portion of their fabric. Although the buds thus produced and separated are usually developed into the likeness of the parent stock, yet this is sometimes not the case, the stock possessing one form, and the bud another which may be quite different; as when certain fixed composite Zoophytes bud-off free-moving solitary Medusæ, these last depositing ova from which the Zoophytic type is regenerated. When, however, this phenomenon, to which the name of 'alternation of generations' has been given (erroneously in the Author's opinion),* is carefully examined, it is found that the bud thus detached is really the generative apparatus of the parent stock, furnished (it may be) with nutrient and locomotive organs of its own; so that neither can be regarded as a complete organism without the other. Thus the Medusa contains the proper generative apparatus of the Zoophyte, which developes no other; and the 'aggregate' Salpæ that are budded-forth from a kind of stalk in the interior of the 'solitary' form, must be regarded as altogether constituting its true generative apparatus, since it never produces any other. In all instances it will be found, that whatever may be the variations which present themselves in the entire history of any species, the immediate product of the true Generative act is uniformly the same.

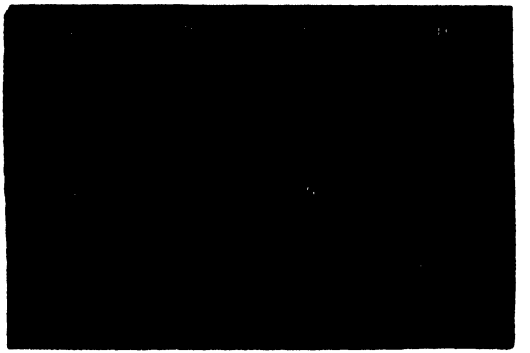
783. This act, in Animals as in Plants, requires the concurrent action of two sets of organs, evolving 'sperm-cells' and 'germ-cells' respectively; and it is curious that these should present the closest approach to those of the higher Cryptogamia, rather than to those of Plants above or below them in the scale. The two sets of organs may be united in the same individual, as they are in most Plants; and the ova may be fertilized from the seminal cells of the same being;—as happens in many Zoophytes, and in some of the lowest tribes of Mollusks. Or, the two sets of organs being present in each individual, it may not be capable of self-impregnation; but, in the

* For a discussion of this subject, see the Author's "Principles of Comparative Physiology," Chap. xi., sect. 1.

congress of two individuals, each impregnates, and is impregnated by, the other;—as may be observed in the Snail and many of the higher Mollusks. Or the sexes may be altogether distinct; one individual possessing only the *male* or spermatic organs, and the other the *female* or germ-nourishing apparatus;—this is observed in the higher classes of the Radiated, Molluscous, and Articulated sub-kingdoms; and it is the case in all Vertebrata.

784. The earliest part of the history of Embryonic Development is nearly the same in all Animals; for it consists in the multiplication of the single cell of which the original germ is composed, until a cluster is formed, all the cells of which appear to be in every respect similar one to another. Each of these cells either takes into itself, or draws around it, a portion of the *vitellus* or yolk, which is the nutrient substance of the ovum; and thus either the whole of this vitellus, or a portion of it, is subdivided into a number of minute spherules, altogether constituting what is known as the 'mulberry mass' (Fig. 146). The former seems to be the

Fig. 146.*



case, when the grade of development of the organism which is to be formed at the expense of the yolk is very low; whilst the latter plan is followed, when the yolk is destined to afford a prolonged

* Successive stages of segmentation in the vitellus of the Ovum of *Ascaris acuminata*:—A, ovum recently impregnated, the yolk-bag slightly separated from the enveloping membrane; B, first fission into two halves; C, second fission, forming four segments; D, yolk, now divided into numerous segments; E, formation of 'mulberry mass' by further segmentation; F, the mass of cells now beginning to show the form of the future worm; G, further progress of its evolution; H, the worm, formed by the conversion of the yolk-cells, now nearly mature.

sustenance to the embryo, which attains a high degree of development whilst supported upon it alone. Thus among the Invertebrata generally, we find that the embryo comes-forth from the egg in a very simple condition, a large part of its structure having undergone but little change from the state of the 'mulberry mass;' and in these the whole yolk undergoes subdivision. The same is the case, too, in the Batrachian Reptiles, which issue from the egg in a form very different from that into which they are to be subsequently developed; and it is the case even with Mammalia, but for a very different reason, their embryonic structure, first formed at the expense of the yolk, being destined to acquire additional material for its full development from a source altogether different. In the highest Mollusks, however, as also in Fishes, ordinary Reptiles, and Birds, the portion of the yolk which undergoes subdivision is comparatively small; and the great mass of the vitellus is destined to be subsequently absorbed into the substance of the germ, by a process analogous to that by which the food of the adult is imbibed. Hence the portion of their yolk which undergoes subdivision, and helps to constitute the 'mulberry mass,' may be termed the 'germ-yolk,' whilst the remainder may be designated as the 'food-yolk.'

785. When the whole of the yolk is taken into the mulberry mass, the formation of the embryo is usually the result of the progressive metamorphosis of its parts; the cells of its surface being converted into the integument, and those of its inner part into the internal organs. This is the case, for example, in the Intestinal Worm, some of the stages in whose development are shown in Fig. 146. The embryonic condition of many of the organs is frequently retained, at the time when the young animal comes-forth from the egg; those parts only being completed, which are necessary to enable it to obtain its nutriment. Other organs are subsequently evolved at the expense of the food thus introduced; and thus a complete change or *metamorphosis* may take-place, in regard alike to external form and to internal structure, between the larval and the adult states. Of this phenomenon we have characteristic examples in the groups of Insects and Batrachia; and although it was formerly considered exceptional, it is now known to be the ordinary occurrence among the lower tribes of animals, comparatively few of which come-forth from the egg under their adult forms. The change is sometimes obviously gradual, as in the progressive advance of the Tadpole into the condition of the Frog; but it is sometimes apparently sudden, as when the Chrysalis-skin is thrown-off, and the perfect Insect comes-forth. In the latter case, however, the change is really just as gradual as in the former; since the organs characteristic of the perfect Insect are undergoing development during the whole of the Chrysalis period, to be displayed and brought into use at its termination. Thus the whole life of the Insect, up to its last change, may be regarded as one of

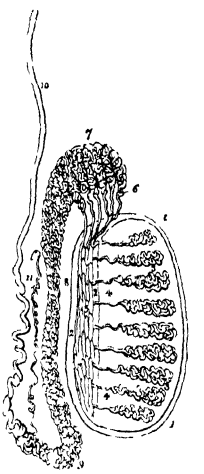
prolonged embryonic development; and the same may be said of that of the Frog, up to the time when its permanent organs are fully evolved.—No such ostensible metamorphosis takes place, however, in any of the animals which are provided with a 'food-yolk;' for this supplies that material for the continued development of the embryo *within* the egg, which is elsewhere to be obtained *out* of it; and thus the embryo is supported, until it has nearly attained its adult *condition*, although far from having acquired its adult *size*. Now in all these cases, it is very interesting to remark that the first *nisus* is towards an extension of the embryonic mass as a membranous expansion (evidently analogous to the cotyledon of the Flowering Plants, § 781) over the 'food-yolk;' in this 'germinal membrane,' which forms a sort of temporary stomach, blood-vessels are developed, which absorb the prepared nutriment and convey it to the permanent portion of the embryonic structure; and when its function is completed, the store of aliment being exhausted, and the proper nutrient apparatus of the embryo being ready for action, we lose sight of it altogether. We shall find that a similar germinal membrane is formed in the Human ovum, although there is no 'food-yolk;' its formation being apparently requisite for ulterior purposes, and the portion of the mulberry mass which gives origin to the permanent part of the embryonic structure being comparatively small.

2. *Action of the Male.*

786. The share in the Reproductive function which belongs to the Male Sex, essentially consists in the formation and liberation of the fertilizing bodies termed *Spermatozoa*. These are prepared within peculiar cells, as already described (§ 241); and the 'sperm cells' are either scattered through the soft parenchyma of the body, as happens among some of the lowest animals; or they are confined to certain parts of it, as in those a little more elevated in the scale; or they are formed within follicles or tubes, clustered-together into an organ of a glandular character, known as the *Testis*. Such an organ is found in all Insects and Mollusks, as well as in Vertebrated Animals. In the first of these classes, it is formed on the general plan of their proper glands (§ 720); being usually composed of tubes, more or less elongated, and sometimes terminating in enlarged follicles. In the Mollusks, on the other hand, it is almost invariably composed of clusters of follicles. In either case, the seminal cells are developed within the tubes or follicles, as are the ordinary secreting cells of the Liver or Kidney within the tubes or follicles of those glands; and their contents are discharged by an excretory duct, which terminates in an organ that conveys them out of the body, either emitting them into the surrounding water (as happens with many Mollusks), or depositing them within the body

of the female. It is curious that in some of the lowest Fishes, we should return to one of the simplest conditions of this organ,—a mass of vesicles, without any excretory duct. In these cases, the secretion formed within the vesicles escapes by their rupture into the abdominal cavity; whence it passes out by openings that lead directly to the exterior.—The *Testis* in Man (Fig. 147) is formed, in every essential particular, upon the plan of the ordinary Glands. It consists of several distinct lobules, separated by processes of the fibrous envelope, or tunica albuginea, which pass down between them; and each lobule consists of a mass of convoluted tubuli seminiferi, through which blood-vessels are minutely distributed. The diameter of these tubuli is tolerably uniform; being, when they are not over-distended, from 1-195th to 1-170th of an inch. They form frequent anastomoses with each other; and on this account it is difficult to trace-out their free or cæcal extremities. The tubuli of each testis discharge their contents into an efferent duct, the Vas deferens; and by this the product is conveyed into the Vesicula seminalis on each side, which, like the gall-bladder and urinary bladder, serves to store-up the secretion until the proper time arrives for discharging it. The product of the action of the Testis consists of a fluid through which the Spermatozoa are diffused; these last bodies being usually set-free by the rupture of the seminal cells, before they leave the tubuli of the testis. It is difficult to determine the precise characters of the fluid portion of the secretion; as this is mingled with other secretions (such as that of the Prostate gland, and of the mucous lining of the Vesiculæ seminales and spermatic ducts,) before it is emitted. And an exact analysis is not of much consequence; since there can be no doubt that the peculiar powers of the fluid depend upon the Spermatozoa. It may

Fig. 147.*



* Plan of the structure of the Testis:—1, 1, the tunica albuginea; 2, 2, the mediastinum testis; 3, 3, the lobuli testis; 4, 4, the vasa recta; 5, the rete testis; 6, the vasa efferentia, of which six only are represented in this diagram; 7, the coni vasculosi, constituting the globus major of the epididymis; 8, the body of the epididymis; 9, the globus minor of the epididymis; 10, the vas deferens; 11, the vasculum aberrans.

be stated, however, that the Spermatic fluid has an alkaline reaction, and that it contains albumen, together with a peculiar animal principle termed Spermatine; and that it also includes saline matter, consisting chiefly of the muriates and phosphates, especially the latter, which form crystals when the fluid has stood for some little time.

787. The *Spermatozoa*, or minute filamentous bodies set-free by the rupture of the spermatic cells, are distinguished by their power of spontaneous movement, which has occasioned them to be long regarded as proper Animalcules. It is now clear, however, from the history of their development, as well as from other considerations, that they cannot be justly regarded in this light; and that they are analogous to the reproductive particles of Plants, which, in many cases, exhibit a spontaneous motion of extraordinary activity, after they have been set-free from the parent structure. The Human Spermatozoon consists of a little oval flattened 'body,' from the 1-600th to the 1-800th of a line in length; from which proceeds a filiform 'tail,' gradually tapering to a very fine point, of 1-50th or at most 1-40th of a line in length. The whole is perfectly transparent; and nothing that can be called structure can be satisfactorily distinguished within it. The movements are principally excited by the undulations of the tail, which give a propulsive action to the body. They may continue for many hours after the emission of the fluid; and they are not checked by its admixture with other secretions, such as the urine and the prostatic fluid. When the seminal fluid remains in contact with a living surface (as when deposited in the generative organs of the female), the Spermatozoa may retain their vitality for some days; and an instance has already been referred-to (§ 240), in which the later stages of the development of the Spermatozoa actually take-place in this situation, —the seminal fluid emitted by the male (among many Crustacea) not containing any Spermatozoa completely formed, but including numerous spermatic cells, which undergo the remainder of their evolution, and then rupture and set-free their contents, within the oviducts of the female.

788. The power of procreation does not exist in the Human Male (except in rare cases) until the age of from 14 to 16 years; at which epoch the sexual organs undergo a much-increased development, and the instinctive desire which leads to the use of them is awakened in the mind. From that time to an advanced age, the procreative power remains, in the healthy state of the system, unless it be exhausted by excessive use, or by too energetic a direction of the mental or corporeal powers to some other object. The formation of Seminal fluid being, like the proper acts of Secretion, very much influenced by conditions of the Nervous System, is increased by the continual direction of the mind towards objects which arouse the sexual propensity; and thus, if sexual intercourse be very frequent,

a much larger quantity of the fluid will be produced, than if it is more rarely emitted, although the amount discharged on each occasion will be less. The formation of this product is evidently a great tax upon the corporeal powers; and it is a well-known fact, that the highest degree of bodily and mental vigour is inconsistent with more than a very moderate indulgence in sexual intercourse; whilst nothing is more certain to reduce the powers, both of body and mind, than excess in this respect.

789. It may be stated as a general law, prevailing equally in the Vegetable and Animal kingdoms,—that the development of the individual, and the reproduction of the species, stand in an inverse ratio to each other. We have seen that in many organized beings, the death of the parent is necessary to the production of a new generation; and even in numerous species of Insects, it follows very speedily upon the sexual intercourse. It is a curious fact, that Insects which usually die, the male almost immediately after the act of copulation, and the female very soon after the deposition of the eggs, may be kept alive for many weeks or even months, by simply preventing the copulation. And there can be no doubt that, in the Human race, early death is by no means an unfrequent result of the excessive or premature employment of the genital organs; and where this does not produce an immediately-fatal result, it lays the foundation of future debility, that contributes to produce any forms of disease to which there may be a constitutional predisposition, especially those of a scrofulous nature.

790. The emission of the Spermatic fluid is an act of a purely *reflex* nature; the Will having no power either to effect or to restrain it. The stimulus is given by the friction of the surface of the Glans Penis against the rugous walls of the Vagina, the sensibility of the organ being at the same time much increased by the determination of blood to it. The impression is at last sufficiently strong to produce, through the medium of the lower part of the Spinal cord (which is the ganglionic centre of the circle of afferent and efferent nerves connected with this organ), a reflex contraction of the muscular walls of the vasa deferentia. These discharge their contents into the urethra; and a like action causes the fluids of the vesiculæ seminales and of the prostate gland (which seem to serve for the dilution of the semen) to be poured into that canal; from which they are expelled with some degree of force, and with a kind of spasmodic action, by its own Compressor muscles. Although the sensations concerned in this act are ordinarily most acutely pleasurable, yet there appears to be sufficient evidence that they are by no means essential to its performance; and that the impression conveyed to the Spinal cord may excite the contraction of the Ejaculator muscles, like other reflex operations, without producing sensation (§ 394).

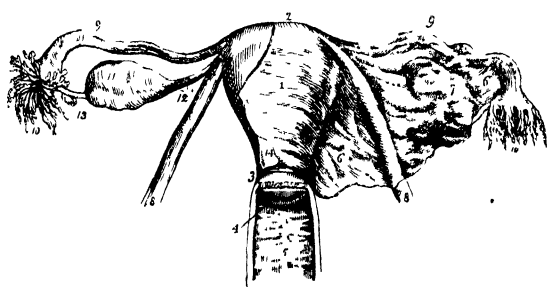
3. *Action of the Female.*

791. The share of the Female in the Generative act is greater than that of the Male; for she not only furnishes, in the 'germ-cell,' a product which is as essential as that supplied by the 'sperm-cell' for the first formation of the germ; but she also supplies it with the materials which it requires for its development, up to the stage at which it can support its own life. The mode in which this is accomplished, is essentially the same with that in which the process is effected in Plants. In certain parts of the female structure are developed peculiar bodies termed *ova;* which contain, not merely the germ-cells, but in addition a store of nutriment adapted to supply the wants of the germ. The fertilizing influence finds its way into these; and the germs thus produced begin to grow at the expense of the material with which they are surrounded. This, as already pointed-out, may enable the embryo to develope itself without any further assistance (save a warm temperature) into the form it is permanently to assume; as in the case of Birds and Reptiles, which do not come-forth from the investments of the egg, until they have attained the form characteristic of the group to which they belong. Or it may only serve for the early part of the process; and one of two methods may then be employed to complete it. Either a new connection is formed between the parent and the embryo, by which the former continues to supply the latter with nutriment more directly from its blood, as is the case with Mammalia: or the embryo issues from the egg, in a condition very unlike that which it is permanently to attain, but in a form which enables it to acquire its own nourishment, and to pass through the latter stages of its evolution quite independently of any assistance from its parent, as is the case with a large proportion of the Invertebrata.

792. The Ova, like the seminal cells, are scattered through the soft parenchyma of the body, in animals of the lowest class; but they are more commonly developed in certain distinct portions of the fabric; being sometimes formed in the midst of solid masses of areolar or cellular texture; whilst in other instances they are developed, like the spermatic cells, in the interior of tubes and vesicles resembling those of glands, and furnished with an excretory duct. The latter condition obtains in the greater proportion of the higher Invertebrated animals, and in some Fishes; but in the Vertebrated classes we return to the type which characterizes the egg-producing organs in many Zoophytes,—namely, the development of the egg in the midst of a mass of solid parenchyma, from which it gradually makes its way to escape into the visceral cavity. The Ovarium of the Mammal, Bird, or Reptile, as well as that of most Fishes, differs entirely, therefore, from that of the Invertebrata; for the latter have all the essential characters of true glands; whilst

the former are nothing else than masses of parenchyma, copiously supplied with blood-vessels, and having dispersed through their substance certain peculiar cells, termed *ovisacs*, within which the ova are developed. In order that the latter may be set-free, not only must the ovisac itself burst (like parent-cells in general), but the peculiar tissue and the envelopes of the ovarium must likewise give-way. When the ova thus escape into the abdominal cavity, they may lie there for some time, at last to be discharged through simple openings in its walls, as happens in those Fishes which have this form of ovarium; or they may be at once received into the trumpet-shaped expansions of tubes that shall convey them to these orifices. These tubes are termed *oviducts*, in common with the excretory ducts of the glandular ovaria of Invertebrated animals; for their function is the same,—that of conveying the ova to the outlet by which they are extruded from the body. They are represented in Mammalia by the Fallopian tubes, which are true oviducts, although they terminate in the uterus instead of proceeding directly to the outlet. And it is by the fimbriated extremities of the Fallopian tubes (Fig. 148, 10, 10), which apply themselves closely to

Fig. 148.*



* The Uterus with its appendages viewed on their anterior aspect:—1, the body of the uterus; 2, its fundus; 3, its cervix; 4, the os uteri; 5, the vagina; the number is placed on the posterior raphé or columna, from which the transverse rugæ are seen passing-off at each side; 6, 6, the broad ligament of the uterus; 7, a convexity of the broad ligament formed by the ovary; 8, 8, the round ligaments of the uterus; 9, 9, the Fallopian tubes; 10, 10, the fimbriated extremities of the Fallopian tubes; on the left side the mouth of the tube is turned forwards in order to show its ostium abdominale; 11, the ovary; 12, the utero-ovarian ligament; 13, the Fallopio-ovarian ligament, upon which some small fimbriæ are continued for a short distance; 14, the peritoneum of the anterior surface of the uterus; this membrane is removed on the left side, but on the right is continuous with the anterior layer of the broad ligament.

the surface of the ovaries at the time of the discharge of the ova, that these are received and conveyed to the uterus, instead of being allowed (as in some of the lower animals) to fall into the abdominal cavity.

793. There are many cases among the lower classes, in which the ovum is retained within the oviducts, so that the young comes into the world alive; and there are a few in which, during this delay, it receives a direct supply of additional nourishment from the fluids of its parent. It is in the Mammalia, however, that we find the most remarkable and complete provision for this purpose. Still, the lowest division of this group approximates closely, in the type of its generative apparatus, to the Oviparous Vertebrata; for the oviducts of the *Monotremata* remain distinct from each other, and terminate separately in the uro-genital canal, each of them having first undergone dilatation into a uterine cavity, so that those animals have two completely-distinct uteri. In the *Marsupialia*, there is a closer approximation of the two lateral sets of organs on the median line; for the oviducts converge towards one another, and meet on the median line, but without coalescing; so that these animals have a true 'double uterus,' opening by two orifices into the vaginal canal, a condition which is sometimes met-with as a malformation in the Human female. The vaginal canal, however, is also double; which is less frequently observed in the Human species. The two preceding orders constitute the sub-class of *Implacental* Mammals; the development of their ova within the uteri being cut-short at a period anterior to the formation of the placenta (§ 818). —As we ascend through the series of *Placental* Mammals, we find the lateral coalescence of the uterine dilatations of the Fallopian tubes becoming more and more complete. It first shows itself in the vagina, which is everywhere single, although a trace of separation into two lateral halves is seen in the Mare, Ass, Cow, Pig, and Sloth, in which animals it is traversed, in the virgin state, by a narrow vertical partition. In many of the Rodentia, the uterus still remains completely divided into two lateral halves, opening into the vagina by separate orifices; whilst in others, these coalesce at their lower portion, forming a rudiment of the true 'body' of the uterus of the Human female. This part increases in the more elevated Herbivora and Carnivora, at the expense of the lateral ununited portions, which are now termed the 'cornua;' but even in the lower Quadrumana the uterus is somewhat cleft at its summit, and the 'angles' into which the oviducts enter, form a considerable part of the whole organ. As we ascend through the Quadrumanous series towards Man, we find the 'body' of the uterus increasing, and the 'angles' diminishing in proportion, until the original division is completely lost-sight-of, except in the slight dilatation of the cavity at the points at which the Fallopian tubes enter it.

794. Having thus briefly noticed the most important characters

of the organs provided for the original production and for the subsequent reception of the ova, we have now to inquire into the history of their development.—The essential structure of the *ovule*, or unfertilized egg, appears to be the same in all animals. It consists externally of a membranous sac, termed, from the nature of its contents, the *vitelline membrane* or 'yolk-bag.' The *vitellus* or 'yolk' consists chiefly of albumen and oil-globules; and floating in this fluid is seen a cell of peculiar aspect, termed the *germinal vesicle*, upon the wall of which is a very distinct nucleus, termed the *germinal spot*.—The layer of albumen surrounding the yolk, and termed the *white* of the Bird's egg, together with the membrane which envelopes this and forms the basis of the shell, are not added until after the ovum has left the ovarium. They are not present in the eggs of many of the lower Invertebrata; these consisting merely of the parts which are formed within the ovarium.

795. The structure of the ovule in Mammals differs in no essential particular from that just described; but the yolk is much less in amount than in the ovules of Invertebrated animals, since only the very earliest stages of the development of the embryo are to take-place at its expense. The vitelline membrane is of peculiar thickness and transparency; and as, when the ovum is compressed under the microscope, it is seen as a broad transparent belt, it is commonly known as the *zona pellucida*. We shall find that the ovule, after leaving the ovarium and receiving the fertilizing influence, becomes enclosed, whilst passing through the Fallopian tube, with a layer of albuminous matter which represents the *white* of the Bird's egg, and with an additional fibrous envelope which corresponds with the membrane that envelopes the latter. This fibrous membrane, termed the Chorion, afterwards becomes subservient, however, to various important changes; by means of which the ovum is again brought into connection with the parent, to derive from the blood of the latter the materials requisite for the continued development of the embryo. These changes will be described hereafter (§§ 811, 818).

796. The Ovisac of Mammalia forms the *inner* layer of what is termed the *Graafian follicle*, after the name of its discoverer; and this, instead of closely enveloping the ovule, as it does in oviparous animals, contains in addition to it a quantity of granular matter, consisting of cells arranged in membranous layers, together with fluid. In the immature ovisac, these cells occupy nearly the whole space between the ovisac and the ovum, but they gradually dissolve away, especially on the side nearest the surface of the ovary; and at the same time an albuminous fluid is effused from the deeper part of the ovisac, which pushes before it the residual layer of cells that immediately surrounds the ovum (forming the *discus proligerus*), and thus carries it against the opposite wall. The *outer* layer of the Graafian follicle is formed by a thickening and condensation of

the surrounding parenchyma of the ovarium; and it is quite distinct from the ovisac which it envelopes. It is extremely vascular, and is evidently destined to afford to the contained structures the materials for their development, which they receive and appropriate by their own powers of absorption and assimilation.

797. The Mammalian Ovarium may be seen, even in the fœtal animal, to contain immature ova, enclosed within their ovisacs; and the several parts of the former may be clearly distinguished in those which are in the more advanced stages of development. It appears that even during the period of childhood, there is a continual rupture of the ovisacs (or parent-cells), and a discharge of ova, at the surface of the ovarium; but these ova never attain so high a degree of development, as to become fit for impregnation. Their evolution takes-place more completely, as well as more rapidly, at the period of puberty, when there is a greatly-increased determination of blood to the genital organs, and a correspondingly augmented energy in their nutritive operations. At this epoch, the parenchyma of the ovarium is crowded with ovisacs; which are still so minute, that in the Ox, according to Dr. Barry's computation, a cubic inch would contain 200 millions of them. Some of those nearest the surface, however, are continually attaining increased development; and a rupture of some of the Graafian follicles, and a discharge of ova prepared for impregnation from the exterior of the ovarium, thenceforth take-place, with more or less tendency to *periodicity*, during the whole time that the female is in a state of aptitude for procreation.

798. In the Human female, the period of Puberty usually occurs between the 13th and 16th years. The differences in the time of its advent partly depend upon individual constitution, and partly upon various external circumstances, such as temperature, habits of life, &c. As a general rule, habitual exposure to a warm atmosphere, an inert life, sensual indulgence, and circumstances that excite the sexual feelings, favour the approach of Puberty; whilst a cold climate and a hardy life retard it. The appearance of the Catamenial discharge usually takes-place whilst the evolution of the genital organs is in progress; and it is a decided indication, when it occurs, that the aptitude for procreation has been attained. It is not unfrequently delayed much longer, however; and its absence is by no means to be regarded as a proof of inability to conceive. The Catamenial fluid, as it proceeds from the lining membrane of the Uterus, seems to be nothing else than blood; but in its passage through the vagina, this is deprived of its coagulating power by admixture with the vaginal mucus, which is remarkable for its very acid character. The appearance of clots in the discharge may usually be regarded as an indication that an excess of blood is escaping from the uterine surface. In some cases of difficult Menstruation, which seem to depend upon a state of

low inflammation in the Uterus, the fibrin has such a tendency to become organized, as to form shreds or layers of false membrane, which sometimes plug-up the os uteri.—It has been recently maintained that this periodical discharge of blood from the lining membrane of the uterus is *dependent* upon the ovarian œstrum; but there seems adequate reason for the belief, that, although the two phenomena are usually consentaneous, yet that they are essentially independent; since each occasionally recurs without being accompanied by the other. The catamenial discharge usually makes its appearance pretty regularly (save during pregnancy and lactation) at intervals of 28 days; but there are many females in whom its recurrence takes-place with no less regularity at shorter or at longer intervals. The duration of the flow, too, is subject to great variations; for in some individuals it does not last above a day or two, whilst in others it continues a week or more.

799. This flux of blood from the lining membrane of the Uterus, is not confined to the Human female, as was formerly supposed; but occurs in some of the lower Mammalia in the state of *heat*, or periodical aptitude for procreation, at which time the ovarium contains ova ready for impregnation. The chief peculiarity attending its appearance in the Human female, is its regular monthly return. In the natural condition of many of the lower Mammalia, as in Oviparous animals, the period of heat recurs at some one time of the year,—usually in the spring; or, in the smaller and more prolific species, from two to six times. And in those which have undergone a change by domestication, the recurrence is usually irregular, depending upon various circumstances of regimen, temperature, &c. The general analogy between the Menstruation of the Human female and the Heat of the lower Mammalia,—consisting in the peculiar aptitude for impregnation which then exists, in consequence of the maturation of ova in the ovarium,—cannot now be questioned; but it appears that, in the Human female, ova *may* be matured and impregnated at *any* part of the period which elapses between the occurrences of the Catamenial discharge; though it is certain that the aptitude for conception is much greater during the few days which precede and follow the menstrual period, than at any intervening time. The duration of the period of aptitude for procreation, which is marked by the continued appearance of the Catamenia, is more limited in Women than in Men; usually terminating at about the 45th year. It is sometimes prolonged, however, for ten or even fifteen years longer; but cases are rare in which women above 50 years of age have borne children. There is usually no menstrual flow during pregnancy and lactation; in fact, the cessation of the Catamenia is usually one of the first signs indicating that conception has taken-place. It is by no means uncommon, however, for them to appear once or twice subsequently to conception; and their appearance during lactation, especially if

it be much prolonged, is still more frequent; hence it might be inferred that the continuance of lactation may not prevent a fresh conception,—which is found to be true in practice.

800. We shall now take a brief survey of the changes which occur in the ovule, when it is being prepared for fecundation; and of the principal features of its subsequent development. The increase of size which is observable in the Ovule that is being prepared for fecundation, is chiefly due to an augmentation in the substance of the yolk; and this also becomes more firm and granular than before. But the most curious change is that which takes place in the germinal vesicle; for this, although previously in the centre of the yolk, now moves-up towards the side of it which is nearest the surface of the ovary, and becomes flattened against the yolk-bag. At the same time, it ceases to present its ordinary pellucidity and becomes obscure; and this alteration appears to be due to the development of a brood of young cells in its interior. From the recent observations of Mr. Newport and others, it would seem that it then bursts and sets these free, so that they become diffused through the yolk; and as this change may happen before fecundation, it must be regarded as being preparatory to it, or at any rate as being independent of it.—Up to the period when the Ovule is nearly brought to maturity, it remains suspended in the centre of the cavity of the Ovisac; but it then begins to move towards that side of the Graafian follicle which is nearest the surface of the ovarium (§ 796). At the same time there is a gradual thinning-away of the various envelopes of the Graafian follicle, as well as of its own walls, in the situation of its most projecting part; and thus it is preparing to give-way at that point, for the discharge of the contained ovum. This discharge is usually accompanied, in the Human female at least, with an effusion of blood into the cavity of the ovisac; and the coagulum which is left, at first of a blackish hue, gradually loses its colouring matter, so as to acquire the aspect of a mere fibrinous clot, and is progressively removed by absorption.

801. An important change is at the same time occurring in the wall of the Graafian follicle itself; for whilst the part with which the ovule comes in contact gradually thins-away, the outer or vascular layer of the remainder, especially on that side most deeply imbedded in the ovary, becomes much increased in thickness; and a great increase takes-place at the same part in the cellular layer that lines the ovisac, which presents a reddish glutinous aspect. This subsequently undergoes a still greater augmentation, and becomes more fleshy; projecting like a mass of granulations from the interior of the ovisac, and receiving blood-vessels which pass into it from the vascular membrane that surrounds it. At the same time, the wall of the Graafian follicle is thrown into wrinkles which are directed towards the interior, so as to occasion the contraction of the cavity; and thus (the blood-clot which previously

filled it being gradually absorbed) it comes to be entirely filled with the new growth, the centre of which is marked by a sort of stelliform cicatrix. This substance speedily becomes of a paler hue than at first, and is known from its colour as the *corpus luteum*.—The escape of the ovule from the ovarium involves processes which are essentially the same, whether it be impregnated or not; but the subsequent changes differ in the two cases, so that the 'corpus luteum' which accompanies the pregnant state is usually a much larger and more highly organized body, than that which is found in the ovary of the unimpregnated female. This difference may be due in part to the absence, in the latter case, of that special determination of blood to the genital organs, which takes-place in the former.—It is obvious, then, that the presence of a *small* and imperfect 'corpus luteum' in the ovary, merely indicates that an ovum has been matured and discharged, and affords no evidence of impregnation or sexual intercourse. The presence of a large and characteristic 'corpus luteum,' on the other hand, may be regarded as affording undoubted evidence that impregnation has taken-place. When fully formed, the 'corpus luteum' may be rather more than half an inch in one of its diameters, and rather less in the other; it usually forms a projection on the surface of the ovary, and occupies from one-fourth to one-half of the whole area of its section. It is frequently, however, much smaller than this; and on the whole it may be said, that the presence of a 'corpus luteum' as large as a full-sized pea, is tolerably certain evidence of impregnation. After delivery, the size of the corpus luteum rapidly diminishes, and in a few months it ceases to be recognizable as such; the cicatrix by which the ovum has escaped, however, remains visible for some time longer.

802. The ovules discharged from the surface of the ovary by the process already described, whether sexual intercourse take-place or not, are received into the Fallopian tubes, and by them conducted towards the uterus. Their transmission may be effected by a kind of peristaltic movement which is observed in these tubes during the period of heat; or, it may be, by the action of the cilia which line them; the direction of both movements being the same,—namely, from the ovaries towards the uterus. If in their course they should not receive the fertilizing influence, they appear soon to die and to disintegrate; but if they should be impregnated by contact with the spermatic fluid, they almost immediately begin to undergo the first of those changes, which tend to the production of a new organism.

803. Much discussion has taken-place, with regard to the exact point at which the fertilization of the ovulum is effected; but this does not seem to be a matter of much consequence, as we find the order of the different steps to vary considerably in different classes of animals. Thus in many aquatic Mollusca, and even in a large proportion of the class of Fishes, there is no act of copulation what-

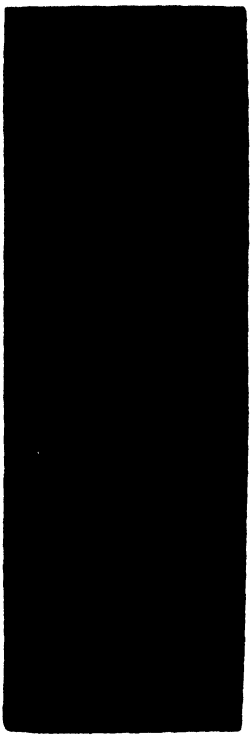
ever; but the spermatic fluid emitted by the male is diffused through the water, and fertilizes the ova which have been deposited by the female in his neighbourhood. In the Frog, again, and in other Reptiles, the spermatic fluid is emitted upon the ova by the male, at the time that they are being extruded by the female. In many Insects and Crustacea, in which a single congress often serves to fertilize many thousand eggs, the deposition of which occupies a period of several weeks or months, the spermatic fluid is received and stored-up in a saccular dilatation of the oviduct of the female, which is termed the *spermotheca;* and in this manner it serves to impregnate the ova as they are successively developed and conveyed to the outlet of the oviduct. In Birds, we find that ova are often set-free from the ovarium in a state of full maturity, but without fertilization; and that they receive their additional layer of albumen and their shelly envelope, in passing down the oviduct, so as, at the time of their deposition, to differ in no obvious particular from fertile eggs. It is doubtful, in regard to Mammalia, whether the act of fertilization takes-place before the ovum has been completely extricated from the ovisac, or subsequently to its finally quitting the ovarium and being received into the Fallopian tube. It is quite certain that the spermatozoa, frequently, if not invariably, find their way to the surface of the ovary, being carried thither by their own spontaneous movements; and it seems on the whole most probable that the fertilization of the ova usually takes-place before they have entirely escaped from the ovisac, or whilst they are still in the commencement of the Fallopian tube. It is not unlikely that the place of the act of fecundation varies, according to the point at which the ovule and the seminal fluid first come into contact,—which may depend upon the degree of maturity of the ova at the period of copulation.

804. Everything indicates that the contact of the Spermatozoa with the Ovule is the one thing needful in the act of fecundation; and the experiments and observations of the late Mr. Newport on the impregnation of the ova of the Frog, leave no reasonable doubt as to the fact, that the process is essentially the same as takes place in those Cryptogamia whose sperm-cells produce self-moving 'antherozoids' (§ 780). For the spermatozoa imbed themselves in the gelatinous envelope of the ovum, within a few seconds after they come into contact with it; they then make their way through the vitelline membrane into the interior of the ovum, where they undergo a gradual diffluence; and thus the product of the sperm-cell is enabled to mingle with that of the germ-cell, so as to lay the foundation of a germ,—the Spermatozoon being nothing else than an embodiment of the fertilizing material developed within the sperm-cell, which is endowed with a temporary power of movement (analogous to that of cilia) in order that it may find its way to the Ovum. It has been ascertained by Mr. Newport, that spermatozoa

whose spontaneous motility has ceased, no longer possess the fecundating power.

805. *Development of the Embryo.*—The first change which can be observed to be consequent upon fecundation in the Mammalian ovum, is the 'segmentation' of the yolk; the entire mass of which, though previously compact and uniform, resolves itself, first into two, then into four, then into eight segments (Fig. 149, A, B, C); each segment containing a transparent vesicle, which may be surmised to be a descendant of the original germ-cell. By a continuance of the same process, the whole cavity of the vitelline sac or zona pellucida becomes occupied by spherical particles of yolk (each containing a pellucid particle), the aggregation of which gives it a mulberry-like appearance; and by its further continuance, the component cells becoming more and more minute, the mass comes to present a uniform finely-granular aspect. At this stage it does not appear that the several segments of the yolk have a distinct enveloping membrane; but an envelope is now formed around each of them, converting it into a cell of which the included particle forms the nucleus. This happens first to the peripheral portions of the mass; and as its cells become fully developed, they arrange themselves at the surface of the yolk into a kind of membrane, at the same time assuming a pentagonal or hexagonal shape from mutual pressure, so as to resemble pavement-epithelium

Fig. 149.*



* Progressive stages in the segmentation of the vitellus of the *Mammalian Ovum*:—A, its first division into two halves; B, subdivision of each half into two; C, further subdivision, producing numerous segments.

(Fig. 150). As the globular masses of the interior are gradually converted into cells, they also pass to the surface and accumulate there, thus increasing the thickness of the envelope already formed

Fig. 150.*

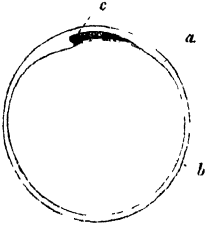
A B



by the more superficial layer of cells; while the central part of the yolk remains, filled only with a clear fluid, which seems to be the produce of the liquefaction of some of the interior spherules. By this process, the external part of the yolk is converted into a kind of secondary envelope, constituting the *germinal membrane;* and as this forms a complete sac enveloping the liquefied yolk of the interior, and as the whole structure of the future embryo originates in its substance, it has been termed by Bischoff the *blastodermic vesicle.*

806. This 'blastodermic vesicle,' very soon after its formation, presents at one point an opaque roundish spot, which is produced by an accumulation of cells and nuclei of less transparency than elsewhere; and it is within this, which is termed the *area germinativa* (Fig. 152, *a g*), that all the structures of the permanent organism originate. When seen in section, this mass of cells presents the aspect shown at Fig. 151, *c*. The 'germinal membrane' increases in extent and thickness by the production of new cells; and it subdi-

Fig. 151.†



* Latter stage in the segmentation of the yolk of the *Mammalian Ovum;*— at A is shown the "mulberry-mass" formed by the minute subdivision of the vitelline spheres; at B, a further increase has brought its surface into contact with the vitelline membrane, against which the spherules are flattened.

† Plan of early *Uterine Ovum*,—within the external ring, or zona pellucida, are the blastodermic vesicle, *a;* the yolk, *b;* and the incipient embryo, *c*.

vides into two layers, which, although both at first composed of cells, soon present distinctive characters, and are concerned in very different ulterior operations. The outer one of these is commonly known as the *serous* layer, and the inner as the *mucous;* the division is at first most evident in the neighbourhood of the area germinativa; but it soon extends from this point, and implicates nearly the whole of the germinal membrane.

807. The area germinativa soon loses the rounded form which it at first possessed, and becomes first oval, and then pear-shaped. Whilst this change is taking-place in it, there gradually appears in its centre a clear space termed the *area pellucida;* and this is bounded externally by a more opaque circle (whose opacity is due to the greater accumulation of cells and nuclei in that part), which subsequently becomes the *area vasculosa.* In the formation of these two spaces, both the serous and mucous layers of the germinal membrane seem to take their share; but the foundation of the vertebral column and nervous centres appears to be laid chiefly if not entirely in the serous layer, whilst the mucous is afterwards concerned more especially in the formation of the nutritive apparatus. Between these, a third layer subsequently makes its appearance; which, as the first vessels of the embryonic structure are formed in it, is termed the *vascular* layer.

808. Thus the first development of the Mammalian embryo is into a sac, enclosing the store of nutriment that has been prepared for it,—in fact, a stomach; and we shall presently see that it is by the agency of the walls of this sac, that the nutrient materials which it encloses are prepared for being appropriated to the development of the more permanent part of the fabric, which is to be evolved from the centre of the 'mulberry mass.' But we may here stop to notice the interesting fact, that the development of the ovum in the *lowest* classes of animals may almost be said to cease at this point; the external layer of the germinal membrane remaining as the integument, the internal layer becoming the lining of the stomach, and the space occupied by the yolk forming the digestive cavity, into which an entrance or *mouth* is formed by the thinning-away of the germinal membrane at a certain point, round which *tentacula* or prolonged lips are usually developed. This is the essential part of the history of development in the simpler Polypes; and we see how remarkably it corresponds with the history of development of the lower Cryptogamic plants, in which the first-formed membranous expansion, or primary frond, remains as the permanent leaf.—In the Mammalia, on the other hand, the greater part of the germinal membrane, and of the cavity which it forms, have a merely temporary purpose; being cast-off, when they have performed their function, like the cotyledons of Flowering Plants.

809. During the time which is occupied by these important

changes, the Ovum passes through the Fallopian tubes, and makes its way into the Uterus. During its transit through the Fallopian tubes, the Mammalian ovum,—like the ovum of Birds in its passage through the oviduct,—receives an additional layer of albuminous matter secreted from the walls of the tube; and this is surrounded by a fibrous membrane, whose structure and mode of formation have been described on a former occasion (§§ 178, 179). The outer layer of this envelope, in the egg of the Bird, is further consolidated by the deposition of particles of carbonate of lime in its areolæ; but it undergoes no higher organization. In the Mammal, however, this new envelope (termed the *Chorion*) is a formation of great importance; being the medium through which the whole subsequent nutrition of the embryo is derived. This is at first taken-in by means of a number of villous processes, proceeding from the entire surface of the Chorion, and giving it a spongy or shaggy appearance; these processes (which are composed of nucleated cells) serve as absorbing radicles, which draw-in the fluids afforded by the parent; and they thus make-up for the early exhaustion of the small supply of nutritious matter stored-up in the ovum itself. The contained embryo appropriates the fluid which is thus imbibed, by simple absorption through its surface; and thus it is nourished, until a more special provision for its development comes into action. The structure of this organ, termed the *Placenta*, cannot be understood, until the concurrent changes in the lining membrane of the Uterus shall have been considered.

810. This mucous membrane, in its natural condition, presents on its free surface the orifices of numerous cylindrical follicles, which are arranged parallel to each other and at right angles to the surface; and in the spaces between these follicles, the blood-vessels form a dense capillary network. When impregnation takes-place, the membrane swells and becomes lax; its capillaries increase in size; the follicles are developed into glandular cavities, and become turgid with a white epithelium; and the interfollicular spaces are crowded with nucleated cells, which fill-up the meshes of the capillary network. In this peculiar condition, the uterine mucous membrane is termed the *Decidua*. At a later period, the decidua may be found to consist of two distinct layers; the *decidua vera*, lining the uterus; and the *decidua reflexa*, covering the exterior of the ovum. Much discussion has taken-place with regard to the mode in which the decidua reflexa originates; and the question cannot even now be considered as determined. The view recently put-forth by Coste is, perhaps, as probable as any. He considers that the ovum, on its entrance into the uterine cavity, is partly imbedded in its thick vascular lining membrane, and that this swells-up around it, like the granulations around the pea in an issue; so that at last the ovum becomes completely invested by the special envelope thus formed, which closes-in around it, constituting

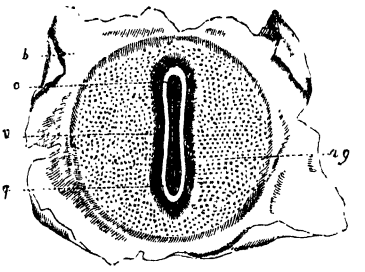
the decidua reflexa, and which is at first not in contact with the decidua vera at any part save where it has sprung from it. As the ovum increases in size, the decidua reflexa grows with it, and is thus gradually brought into contact with the decidua vera which lines the uterus, the cavity between them being obliterated; and at a later period the two coalesce, so that they become no longer distinguishable from each other.

811. When the ovum has arrived in the Uterus, therefore, and the villous tufts of its chorion are developed, these come into contact, in the first instance, with the epithelial layer which intervenes between them and the vascular decidua. Through this cellular membrane, therefore, the ovum must derive its nutriment from the vascular surface; and it cannot be deemed improbable, that its office is to draw from the subjacent vessels the materials which are to serve for the nutrition of the ovum, and to present it to the villous tufts of the Chorion. Each of these, as already mentioned, is composed of an assemblage of nucleated cells, which are found in various stages of development; and the villus seems to elongate by the development of new cells at its free extremity, whilst, like the spongiole of the plant, it draws-in nutriment from the soil in which it is imbedded. On the other hand, the Decidua at this early period appears to be actively employed in preparing nutriment for the embryo; for its cellular layer is so abundant as to form a bed into which the tufts of the chorion are received; whilst its follicles are enlarged into glandulæ of sufficient size to allow these villi (in some Mammals at least) to extend themselves into their interior.—In its earliest grade of development, as already remarked, the chorion and its villi contain no vessels; and the fluid drawn-in by the tufts is communicated to the embryo, by the absorbing powers of its germinal membrane. But when the tufts are penetrated by blood-vessels, and their communication with the embryo becomes much more direct, the means by which they communicate with the parent are found to be essentially the same;—namely, a double layer of cells, one layer belonging to the fœtal tuft, the other to the vascular maternal surface (§ 818).

812. We now return to the Embryo itself; the general history of whose development has been already traced, up to the period at which the cluster of cells in the Area Germinativa is about to give origin to the permanent structures of the fœtus. The parts first formed in the embryo of Vertebrated animals, are such as most characteristically distinguish them from all others;—namely, the Vertebral Column and Spinal Cord. The first indication of these consists in the formation of what is termed the *primitive trace*, which is a shallow groove, lying between two oval ridges (Fig. 152, *v*), known as the *laminæ dorsales*. The form of these is changed with that of the area pellucida; at first they are oval, then pear-shaped, and at last become of a violin-shape. At the same time, they rise

more and more from the surface of the area pellucida, so as to form ridges of higher elevation, with a deeper groove between them; and the summits of these ridges tend to approach one another, and gradually unite, so as to convert the groove into a tube. It is

Fig. 152.*



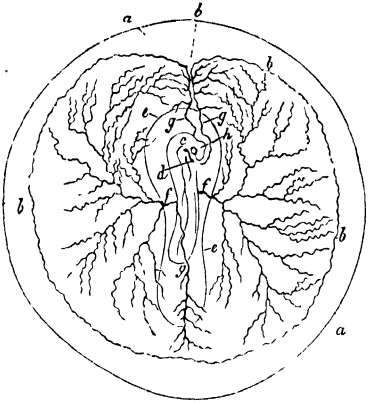
within this that the Cerebro-spinal Axis is afterwards formed; the brain being developed in the anterior dilated portion, and the spinal cord in the posterior more contracted part. The former remains unclosed much longer than the latter. The position of the future bodies of the vertebræ is indicated at this period by a distinct cylindrical rod of nucleated cells (Fig. 17), termed the *Chorda dorsalis;* and this retains its embryonic type in many of the lower Fishes, which never possess a true vertebral column. The elements of the vertebræ are developed in a fibrous membrane, with which the chorda dorsalis subsequently becomes invested; the neural arches being the parts first formed.

813. During the progress of this change, another very important one is taking-place, which has reference to the nutrition of the embryo during its further development. This is the formation of *vessels* in the substance of the germinal membrane; which vessels serve to take-up the nourishment supplied by the yolk, as well as that derived from the chorion externally, and to convey it through the tissues of the embryo. These vessels are first seen in that part of the vascular lamina of the germinal membrane, which immediately surrounds the embryo; and they form a network bounded by a circular channel, which is known under the name of the

* The germ and surrounding parts, from a more advanced *Uterine Ovum*. —*b*, blastoderma, or germinal membrane; *a g*, area germinativa; *c*, cephalic extremity of the germ; *v*, one of the laminæ dorsales; *q*, caudal extremity.

Vascular Area (Fig. 153). This gradually extends itself, until the vessels spread over the whole of the germinal membrane. The vessels are probably formed by the coalescence of the original cells of the layer; and the first blood-discs which they contain seem to originate in the nuclei of these cells. This network of vessels serves to receive the nutritious matter contained in the yolk-bag, and to convey it to the embryo; but the act of absorption seems to be performed here as elsewhere, by cells, a layer of which always intervenes between the vascular layer and the yolk itself. These cells probably correspond in function with those of the villi of the intestinal canal in the adult (§ 238); as the vessels of the yolk-bag,

Fig. 153.*



or temporary digestive cavity, represent those of the alimentary canal to be afterwards developed from a portion of it. The vessels of the yolk-bag terminate in two large trunks, which enter the embryo at the point that afterwards becomes the umbilicus, and which are known as the *Omphalo-Mesenteric*, *Meseraic*, or *Vitelline* vessels (Fig. 157, *q*, *r*). The first movement of fluid takes-place *towards* the embryo; and this may be witnessed before any distinct heart is evolved.

* Vascular area of *Fowl's Egg*, at the beginning of the third day of incubation;—*a*, *a*, yolk; *b*, *b*, *b*, *b*, venous sinus bounding the area; *c*, aorta; *d*, punctum saliens, or incipient heart; *e*, *e*, area pellucida; *f*, *f*, arteries of the vascular area; *g*, *g*, veins; *h*, eye.

814. The formation of the Heart takes-place in a thickened portion of the Vascular layer; by the liquefaction of the interior of a mass of cells, of which the exterior constitute the first walls of the cavity. These gradually acquire firmness and consistency, and are endowed with a contractile power that enables them to execute regular pulsations. In this early condition, the heart is known as the *punctum saliens* (*d*, Fig. 153). The first appearance of the heart in the Chick is at about the 27th hour; the time of its formation in Mammalia has not been distinctly ascertained.

815. Concurrently with the formation of the vascular system, the production of the permanent Digestive cavity commences. This originates in the separation of a small portion of the yolk-bag lying immediately beneath the embryo, from the general cavity, in the following manner.—At about the 25th hour of incubation, in the Fowl's egg, the parts of the germinal membrane which lie beyond

Fig. 154.*

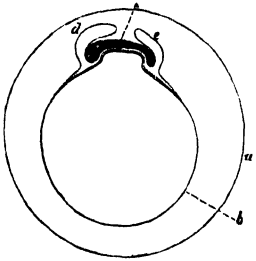
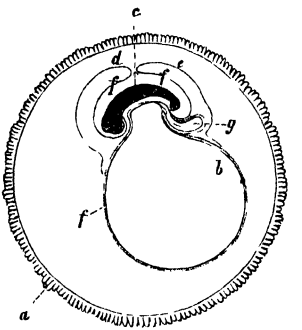


Fig. 155.†



the extremities, and which spread-out from the sides of the embryo, are doubled-in, so as to make a depression upon the yolk; and their folded edges gradually approach one another under the abdominal surface of the embryo, so as at last to meet and enclose a cavity, which is at first simple in its form, but which is subse-

* Diagram of *Mammalian Ovum* at later stage; the digestive cavity beginning to be separated from the yolk-sac, and the amnion beginning to be formed:—*a*, chorion; *b*, yolk-sac; *c*, embryo; *d* and *e*, folds of the serous layer rising-up to form the Amnion.

† The Amnion in process of formation, by the arching-over of the serous lamina:—*a*, the chorion; *b*, the yolk-bag, surrounded by serous and vascular laminæ; *c*, the embryo; *d*, *e*, and *f*, external and internal folds of the serous layer, forming the amnion; *g*, incipient allantois.

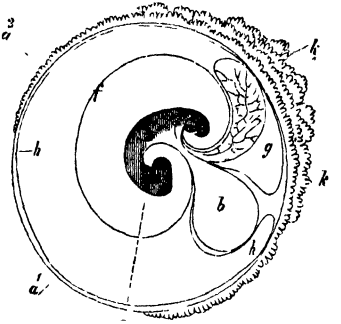
quently rendered more complex by the prolongation and involution of its walls in various parts, so as to form the stomach and intestinal tube (Figs. 154, 155, 156). This digestive cavity communicates for some time with the yolk-bag (from which it has been thus as it were pinched-off), by a wide opening, that is left by the imperfect meeting of the folds of the germinal membrane which constitute its walls. In the Mammalia, this orifice is gradually narrowed, and is at last completely closed; and the yolk-bag, thus separated, is afterwards thrown-off. It may be detected, however, upon the umbilical cord, up to a late period of pregnancy, and is known as the *Umbilical vesicle* (Fig. 157, *l*). In Birds, and other oviparous animals, the whole of the yolk-bag is ultimately drawn into the abdomen of the embryo; the former gradually shrinking as its contents are exhausted, and the latter enlarging so as to receive it as a little pouch or appendage. In Fishes, the hatching of the egg very commonly takes-place before the process has been completed, so that the little Fish swims-about with the yolk-bag hanging from its body.

816. Whilst these processes are going-on in the vascular and mucous layers of the Germinal membrane, a remarkable change is taking-place in that portion of the Serous lamina which surrounds the Area pellucida. This rises-up on either side in two folds (Fig. 156); and these gradually approach one another, at last meeting in the space between the general envelope and the embryo, so as to form an additional investment to the latter. As each fold contains two layers of membrane, a double envelope is thus formed; of which the outer layer (Fig. 155, *d*, *e*, and Fig. 156, *h*) afterwards adheres to the inner surface of the chorion, the original yolk-bag or 'zona pellucida' being now lost-sight-of; whilst the inner one (Fig. 155, *f*, *f*, and Fig. 156, *f*) remains as a distinct sac, to which the name of *Amnion* is given. This takes-place during the third day in the Chick; but the period at which it occurs in the Human Ovum has not yet been clearly ascertained.

817. The embryo, like the adult, has need of Respiration, in order that the carbonic acid set-free in the nutritive operations may be removed from its fluids. In Fishes, the surrounding water acts with sufficient power upon the vessels of the yolk-bag, to produce the required aeration, up to the time when the gills of the young animal are ready to come into play. But in the higher oviparous animals, whose development proceeds further before they leave the egg, a more special provision is made for the purpose. A bag, termed the *allantois*, sprouts (as it were) from the lower end of the body (Fig. 155, *g*); and gradually enlarges, passing round the embryo (Fig. 156, *g*), so as in Birds almost completely to enclose it, intervening between the germinal membrane and the shell, and receiving the direct influence of the air that penetrates the latter. It is thus the temporary lung of the air-breathing oviparous animal;

and it serves for the aeration of its fluids, up to the time when it quits the egg. In the ovum of the Mammal, the chief office of the allantois is to convey the vessels of the embryo to the chorion; and its extent bears a pretty close correspondence with the extent of surface through which the chorion comes into vascular connection with the decidua,—this extent varying considerably in the different orders of Mammalia. Thus in the Carnivora, whose placenta extends like a band around the whole ovum, the allantois also lines the whole inner surface of the chorion, except where the umbilical

Fig. 156.*



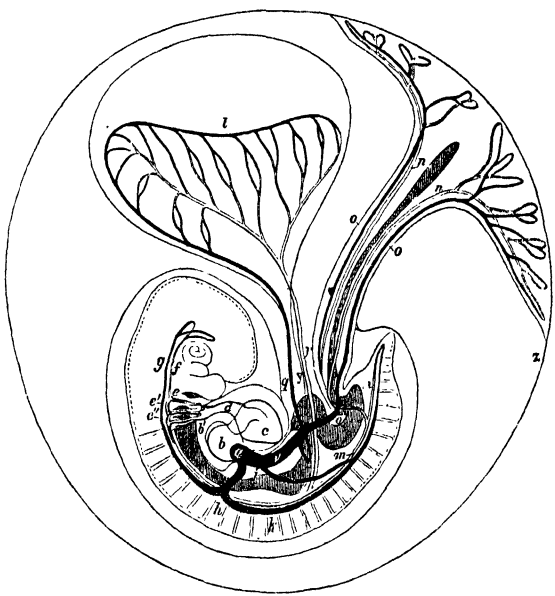
vesicle comes into contact with it. On the other hand, in Man and the Quadrumana, whose placenta is restricted to one spot, the allantois conveys the fœtal vessels to one portion only of the chorion (Fig. 157), although, according to Coste, it completely surrounds the embryo. When these vessels have reached the Chorion, they ramify in its substance, and send filaments into its villi; and in proportion as these villi form that connection with the uterine structure which has been already described (§ 811), do the vessels increase in size. They then pass directly from the fœtus to the chorion; and the allantois, which is no longer of any use, ceases to present itself as a distinct sac. During its existence, however, it serves as a temporary receptacle for the urinary secretion, that is formed in the first place by the Corpora Wolffiana, and afterwards by the true

* Diagram representing a *Human Ovum* in second month:—*a* 1, smooth portion of chorion; *a* 2, villous portion of chorion; *k*, *k*, elongated villi, beginning to collect into Placenta; *b*, yolk-sac or umbilical vesicle; *c*, embryo; *f*, amnion (inner layer); *g*, allantois; *h*, outer layer of amnion coalescing with chorion.

kidneys. The permanent urinary bladder is commonly said to be the lower portion of the Allantois, pinched-off (as it were) from the rest; but this organ really originates in the upper part of the 'uro-genital sinus,' into which, in the early Human embryo, as in the lower Mammalia, the ureters and the sexual ducts discharge themselves in both sexes alike; and the urachus or suspensory ligament of the bladder is the shrivelled remnant of a duct, by which the 'uro-genital sinus' originally communicated with the Allantois.

818. The connection which is thus formed between the Vascular

Fig. 157.*



* Diagram of the Circulation in the *Human Ovum*, at the commencement of the formation of the Placenta:—*a*, venous sinus receiving all the systemic veins; *b*, right auricle; *b'*, left auricle; *c*, right ventricle; *d*, bulbus aorticus, subdividing into *e*, *e'*, *e''*, branchial arteries; *f*, arterial trunk formed by their confluence; *g*, vena azygos superior; *h*, confluence of the superior and inferior azygos; *j*, vena cava inferior; *k*, vena azygos inferior; *m*, descending aorta; *n*, *n*, umbilical arteries proceeding from it; *o*, umbilical vein; *q*, omphalo-mesenteric vein; *r*, omphalo-mesenteric artery, distributed on the walls of the vitelline vesicle *l*; *v*, ductus venosus; *y*, vitelline duct; *z*, chorion.

system of the fœtus and that of the parent, is the only one that exists in the lower Mammalia; which are thus properly designated as 'non-placental.' Each villus of the Chorion contains a capillary loop; this is enclosed in a layer of cells; and this again in a lamina of basement-membrane;—the whole forming the *fœtal* tuft. This comes into contact with the cellular decidua, which lies upon the basement-membrane covering the vascular layer of the decidua. Now the Placenta is composed of these very elements, arranged in a more complex manner. It is formed by an extension of the vascular tufts of the Chorion at certain parts; and a corresponding adaptation, on the part of the Uterine structure, to afford to these an increased supply of nutritious fluid. These specially-prolonged portions are scattered, in the Ruminants and some other Mammalia, over the whole surface of the Chorion, forming what are termed the 'cotyledons;' but in the higher orders, and in Man, they are concentrated in one spot, forming the Placenta. In some of the lower tribes, the maternal and fœtal portions of the placenta may be very easily separated; the former consisting of the thickened decidua; and the latter being composed of the prolonged and ramifying vascular tufts of the Chorion, which dip-down into it. But in the Human placenta, the two elements are mingled together through its whole substance.

819. The *fœtal* portion of the Placenta consists of the branches of the umbilical vessels; which subdivide at the point at which they enter the mass, and form, by their minute ramifications, a

Fig. 158.*

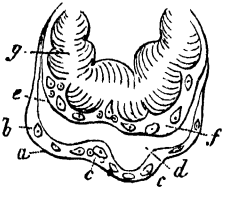
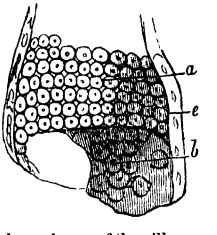


Fig. 159.†

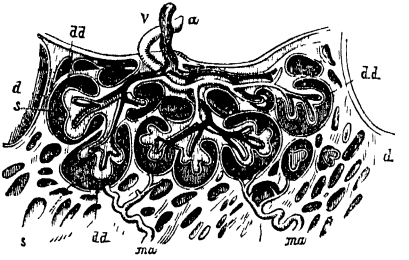


* Extremity of a Placental villus:—*a*, external membrane of the villus, continuous with the lining membrane of the vascular system of the mother; *b*, *c*, external cells of the villus, belonging to the placental decidua; *d*, the space between the maternal and fœtal portions of the villus; *e*, the internal membrane of the villus, continuous with the external membrane of the chorion; *f*, the internal cells of the villus, belonging to the chorion; *g*, the loop of umbilical vessels.

† Portion of the external membrane, with the external cells, of a Placental villus;—*a*, cells seen through the membrane; *b*, cells seen from within the villus; *e*, cells seen in profile along the edge of the villus.

large part of its substance. Each villus contains a capillary vessel, which forms a series of loops, communicating with an artery on the one side, and with a vein on the other; but the same capillary may enter several villi, before re-entering a larger vessel. The vessels of the villi (Fig. 158, *g*) are covered, as in the chorion, by a layer of cells (*f*), enclosed in the basement-membrane (*e*); but the fœtal tuft thus formed is enclosed in a second series of envelopes (*a*, *b*, *c*), derived from the maternal portion of the placenta; a space (*d*) being left between the two, however, at the extremity of the tuft. The vascular tufts not unfrequently extend beyond the uterine surface of the placenta, and dip-down into the uterine sinuses themselves, where they are bathed in the maternal blood.—The *maternal* portion of the placenta may be regarded as a large sac, formed by a prolongation of the internal coat of the great uterine vessels. Against the fœtal surface of this sac, the tufts just described may be said to push themselves, so as to dip-down into it, carrying before them a portion of its thin wall, which constitutes a sheath to each tuft. In this manner, the whole interior of the placental cavity (Fig. 160) is intersected by numerous tufts of fœtal vessels,

Fig. 160.*

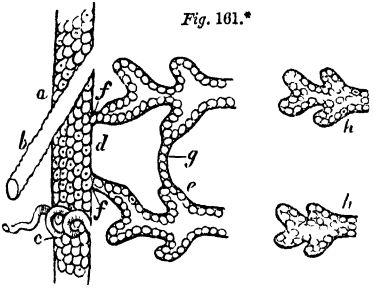


disposed in fringes, and bound-down by the membrane that forms its proper wall; just as the intestines are covered and held in their places by the peritoneum. Now as this dilatation of the uterine blood-vessels carries the decidua before it, every one of the vascular tufts that dips-down into it will be covered with a layer of the cellular structure of the latter (Fig. 159, and Fig. 161, *e*); and this will also form a part of all the bands that connect and tie

* Diagrammatic section of the Placenta, showing the relation of its Fœtal and Maternal portions:—*a*, branch of umbilical artery; *v*, branch of umbilical vein; *ma*, *ma*, maternal (curling) arteries, bringing blood into *s*, *s*, the maternal sinuses; *d*, their decidual lining; *d d*, decidual covering of the fœtal tufts.

down the tufts (Fig. 161, *g*). The blood is conveyed into the cavity of the placenta by the 'curling arteries,' so named from their peculiar course (Figs. 160, *m a*, 161, *c*), which proceed from the arteries of the uterus; and it is returned by large short straight trunks, which pass obliquely through the decidua (Fig. 161, *b*), and discharge their contents into the great uterine sinuses.

Fig. 161.*



820. There is no more direct communication between the Mother and Fœtus than this; all the observations which have been supposed to prove a direct vascular continuity, being certainly fallacious. The function of the Placenta is manifestly double. The fœtal tufts draw from the maternal blood the materials which are required for the nutrition of the embryo,—these materials having been first selected and partially elaborated by the two sets of intervening cells; and in this character, the fœtal tufts resemble the villi of the intestinal surface, which dip-down into the fluids of the alimentary canal, and absorb the nutritive material which they furnish. But the Placenta also serves as a respiratory organ; aerating the blood of the fœtus, by exposing it to the influence of the oxygenated blood of the mother: and in this respect the fœtal tufts bear a close correspondence with the gills of aquatic animals, bringing the blood into relation with a surrounding fluid medium containing oxygen, which is imbibed by the blood in exchange for

* Diagram illustrating the arrangement of the Placental Decidua —*a*, decidua in contact with the interior of the uterus; *b*, venous sinus passing obliquely through it by a valvular opening; *c*, a curling artery passing in the same direction; *d*, the lining membrane of the maternal vascular system, passing-in from the artery and vein, lining the bag of the placenta, and covering *e*, *e*, the fœtal tufts, passing-on to them from their stems from the fœtal side of the cavity, also by the terminal decidual bars *f*, *f*, from the uterine side, and from one tuft to the other by the lateral bar, *g*; *h*, *h*, separated fœtal tufts, showing the internal membrane and cells, which, with the loops of umbilical vessels, constitute the true fœtal portion of the tufts.

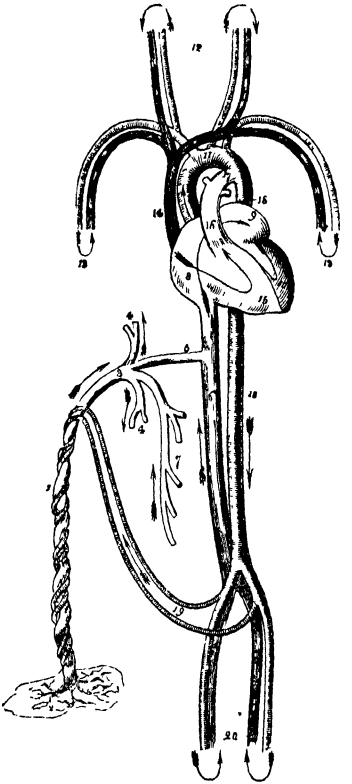
the carbonic acid given-off. And it is probable, too, that the Placenta is to be regarded as an excreting organ; serving for the removal, through the maternal blood, of excrementitious matter, whose continued circulation in the blood of the fœtus would be prejudicial to it.

821. The formation of the Human Placenta commences in the latter part of the second month of utero-gestation; during the third, the organ acquires its proper character; and it subsequently goes-on increasing, in accordance with the growth of the ovum. The vessels of the Uterus undergo great enlargement throughout, but especially at the part to which the Placenta is attached; and the blood in moving through them produces a peculiar murmur, which is usually audible with distinctness at an early period of pregnancy, and which may be regarded (when due care is taken to avoid sources of fallacy) as one of its most unequivocal physical signs. The sound is most commonly heard near the situation of the Fallopian tube of the right side; and it corresponds with the pulse of the mother.

822. It would be inconsistent with the character and objects of this Treatise, to follow, in any detail, the history of the development of the Fœtus during its intra-uterine life; and a general account of the evolution of most of the chief organs has been given in connection with that of their structure. The condition of the Circulating apparatus, however, at the period of birth, deserves especial notice. A general account of the development of the simple pulsating trunk which constitutes its first form, into the four-cavitied heart of the higher Vertebrata, and of the conversion of the single trunk proceeding from it, with its four pairs of branchial arches, into the aorta and pulmonary arteries, with their chief subdivisions, has been already given (§ 566). Up to the time of birth, however, the partition between the auricles is incomplete; a large aperture, the *foramen ovale*, still existing in it. There is also a direct communication between the pulmonary artery and the aorta, by the *ductus arteriosus;* and another direct channel between the umbilical vein and the vena cava, by the *ductus venosus.*

823. The following is the course of the Circulation of the Blood in the Fœtus. The fluid brought from the Placenta by the umbilical vein (Fig. 162, 3), is partly conveyed at once to the vena cava ascendens, by means of the ductus venosus (5), and partly flows through two trunks (4, 4), that unite with the portal vein (7) returning the blood from the intestines, into the substance of the liver, thence to be returned to the vena cava by the hepatic vein. Having thus been transmitted through the two great depurating organs, the placenta and the liver, the blood that enters the vena cava is purely arterial in its character; but being mixed in the vessels with the venous blood that is returned from the trunk and lower extremities, it loses this character in some degree, by the

Fig. 162.*



* The Fœtal Circulation.—1, The umbilical cord, consisting of the umbilical vein and two umbilical arteries, proceeding from the placenta (2); 3, the umbilical vein dividing into three branches, two (4, 4) to be distributed to the liver, and one (5) the ductus venosus, which enters the inferior vena cava (6); 7, the portal vein, returning the blood from the intestines, and uniting with the right hepatic branch; 8, the right auricle, the course of the blood being denoted by the arrow proceeding from 8 to 9, the left auricle; 10, the left ventricle, the blood following the arrow to the arch of the aorta (11), to be

time that it reaches the heart. In the right auricle, which it then enters, it would also be mixed with the venous blood which is brought-down from the head and upper extremities by the descending cava; were it not that a very curious provision exists, to impede (if it does not entirely prevent) any further admixture. This consists in the arrangement of the Eustachian valve, which directs the *arterial* current (that flows upwards through the ascending cava) into the *left* side of the heart, through the foramen ovale, whilst it directs the *venous* current (that is being returned by the descending cava) into the *right* ventricle. When the ventricles contract, the arterial blood contained in the left is propelled into the ascending Aorta, and supplies the branches that proceed to the head and upper extremities, before it undergoes any further admixture: whilst the venous blood contained in the right ventricle, is forced into the Pulmonary artery, and thence through the ductus arteriosus (17) which is like a continuation of its trunk, into the descending aorta, mingling with the arterial current which that vessel previously conveyed, and thus supplying the trunk and lower extremities with a mixed fluid. A portion of this is conveyed, by the umbilical arteries, to the Placenta; in which it undergoes the renovating influence of the maternal blood, and from which it is returned in a state of purity.

824. Hence the head and superior extremities, whose development is required to be in advance of that of the lower, are supplied with blood nearly as pure as that which returns from the placenta; whilst the rest of the body receives a mixture of this with what has previously circulated through the system. The Pulmonary arteries convey little or no blood through the lungs; the current of blood propelled from the right ventricle, passing directly onwards through the ductus arteriosus into the aorta.—At birth, however, the course of the circulation undergoes great changes, that it may be adapted to the new mode in which the infant is henceforth to obtain its nutrition and to carry-on its respiration. As soon as the lungs are distended by the first inspiration, a portion of the blood of the pulmonary artery is diverted into them, and there undergoes

distributed through the branches given-off by the arch to the head and upper extremities; the arrows 12 and 13, represent the return of the blood from the head and upper extremities through the jugular and subclavian veins, to the superior vena cava (14), to the right auricle (8), and in the course of the arrow through the right ventricle (15), to the pulmonary artery (16); 17, the ductus arteriosus, which appears to be a proper continuation of the pulmonary artery; the offsets at each side are the right and left pulmonary artery cut-off, which are of extremely small size as compared with the ductus arteriosus; the ductus arteriosus joins the descending aorta (18, 18), which divides into the common iliacs, and these into the internal iliacs, which become the hypogastric arteries (19), and return the blood along the umbilical cord to the placenta; while the other divisions, the external iliacs (20), are continued into the lower extremities, the arrows at the terminations of these vessels marking the return of the venous blood by the veins to the inferior cava.

aeration; and, as this proportion increases with the full activity of the lungs, the ductus arteriosus gradually shrinks, and its cavity finally becomes obliterated. At the same time, the foramen ovale is closed by a valvular fold; and thus the direct communication between the two auricles is cut-off. When these changes have been accomplished, the circulation which was before carried-on upon the plan of that of the higher Reptiles (§ 563), becomes that of the complete warm-blooded animal; all the blood which has been returned in a venous state to the right side of the heart, being transmitted through the lungs before it can reach the left side, or be propelled from its arterial trunks.—It is by no means unfrequent, however, for some arrest of development to prevent the completion of these changes; and various malformations, involving an imperfect discharge of the circulating and respiratory functions, may hence result.

825. *Parturition.*—The average length of time which elapses between Conception and Parturition in the Human female, appears to be 280 days, or 40 weeks. There can be little doubt, however, that Gestation may be occasionally prolonged for one, two, or even three weeks, beyond that period; such prolongation not being at all unfrequent amongst the lower animals, and numerous well-authenticated instances of it in the Human female being upon record. Upon what conditions this departure from the usual rule is dependent, has not yet been ascertained; but it is a remarkable circumstance, ascertained by the observations of cattle-breeders, that the *male* has an influence upon the length of gestation,—a large proportion of cows in calf by certain bulls exceeding the usual period, and a small proportion falling short of it. In such cases, we must attribute the prolongation of the period to some peculiarity in the embryo, derived from its male parent.

826. The shortest period at which Gestation may terminate, consistently with the life of the child, has not been precisely ascertained; the difficulty of determining the precise date of conception being usually such, in this case as in the preceding, as to prevent the exact length of the Gestation from being known. Thus, the commencement of pregnancy being fixed by the time of the cessation of the Catamenia, when there is no more definite guide, it is obvious that the act of Conception may have taken-place during any part of the interval that has elapsed since the last monthly period; and thus a doubt may exist as to the length of the gestation, to the extent of from one to three weeks. There are very satisfactory cases on record, in which, from the degree of development of the infant at birth, as well as from other circumstances, it might be certainly known not to have attained 26 or 27 weeks, or little more than six months; and in which, by careful treatment, the infant was reared in a condition of health and vigour. And there is reason to believe, that infants have lived for some time,

and might probably have been reared under better management, which were born as early as the 24th or 25th week.

827. The act of Parturition, by which the fœtus is expelled from the Uterus, is accomplished in part by the contractile power of the uterus itself, and in part by the combined operation of the various muscles which press upon the abdominal cavity, and which effect the expulsion of the fæces and urine. No definite account can be given of the reasons why this change should take-place at the period which has been mentioned as its usual date; but we are as much in the dark in regard to other *periodic* phenomena of Animal life; and we must probably look for its source in the maturation of the placental structure, which prepares it for detachment (like the dropping-off of a ripe fruit), and in the complete evolution of the contractile tissue of the uterus, the contractions of which may be considered to commence spontaneously when it has attained a certain epoch in its growth, just as do those of the heart in the embryo (§ 814). For some days previously to the commencement of labour, there is usually a slow contraction of the fibres of the fundus and body of the uterus, and a yielding of those of the cervix; so that the child lies lower, and the size of the abdomen diminishes. This slow contraction is probably dependent, not upon any act of the nervous system, but upon the *direct* excitement of the contractility of the muscular substance of the uterus. When labour properly commences, however, the Spinal system of nerves comes into play, and the uterine contractions are of a reflex nature. As before, however, the act of contraction is confined to the fundus and body of the uterus; the fibres of the cervix uteri and of the vagina being in a state of relaxation, which allows them to yield to the pressure of the child's head. In the first stage of labour, the uterine contractions appear to be alone concerned; and it is not until the head of the child is passing through the os uteri and is entering the vagina, that the assistance of the abdominal muscles is called-in. These act, in the first instance, as in ordinary expiration; but their power is much increased by the voluntary retention of the breath, so that the whole of their contractile force may be applied to the expulsion of the fœtus. In a later stage of labour, this retention of the breath becomes involuntary, during the accession of the 'pains;' and the expulsion of the fœtus is commonly effected with considerable force, especially if the previous resistance has been excessive.

828. The same action which expels the fœtus, usually detaches the placenta; and if the uterus contract with sufficient force after this has been thrown-off, the orifices of the vessels which communicated with it are so effectually closed, that little or no hemorrhage from that source takes-place. When efficient contractions do not occur, they may frequently be excited by pressure upon the uterus itself, by the application of cold to the abdominal surface, to the

extremities, and (in severe hemorrhage) to the entire body, or by the application of the child to the nipple, which will frequently at once succeed in producing the desired effect. The efficacy of these means,—the latter in particular,—obviously depends upon the influence of the spinal cord and its nerves upon the muscular fibres of the uterus; the application of cold to the surface, or the irritation of the nipple, occasioning a reflex action in the uterus. But it is probable that this organ has also considerable power of contracting, independently of the nervous system; thus there are well-authenticated cases on record, in which the fœtus has been expelled after the *somatic* death (§ 64) of the parent; which must have been in consequence of the persistence of the independent contractility of the uterus, and the relaxed state of all the parts through which the child had to make its exit.

829. The cause of the occasional occurrence of the parturient efforts at an unusually-early period, is as little understood as that of their ordinary action. There are some individuals, in whom this regularly happens at a certain month; so that it seems to be an action natural to them. In many cases, however, it may be traced to some undue exertion of body, or mental excitement; and not unfrequently to a general constitutional irritability, which renders the system liable to be deranged by very trifling causes. Premature labour is always to be prevented, if possible, being injurious alike to both mother and child; and for this prevention we have chiefly to rely upon rest and tranquillity of mind and body, and upon the careful avoidance of all those exciting causes, which are liable to produce uterine contractions by their operation upon the nervous system; whilst, at the same time, any measures which will invigorate the body, without stimulating it, should not be overlooked.

830. *Lactation.*—A peculiar preparation is made, in the females of the class Mammalia, for the sustenance of the infant during a long period after birth. This consists in the secretion of a fluid, from the glands termed *Mammary*, which contains all the elements that are required for the development of the body of the infant during the first year. These glands present themselves in an almost rudimentary state, in some of the non-placental animals of the class; consisting only of a few large follicles, which open separately upon the surface (Fig. 117). In the higher Mammalia, however, we find it composed of vast numbers of minute follicles, clustered together upon excretory ducts. The general arrangement of these, in the human subject, is seen in Fig. 163; and the character of the follicles themselves, and of the secreting epithelial cells they contain, as seen under a much higher magnifying power, has been already shown in Fig. 122. Each Mammary gland consists of a number of glandulæ, which are held together by areolar and fibrous tissue; this arrangement may probably have reference to the

mobility which it is requisite that the different parts of the mass should possess, one upon the other, in consequence of its situation upon the pectoralis muscle. The ducts converge and unite together, so as at last to form ten or twelve principal trunks, which terminate in the nipple. At the base of the nipple, these tubes dilate into reservoirs, which extend beneath the areola, and to some distance into the gland, when the breast is in a state of lactation. These, which are much larger in many of the lower Mammalia than they are in the Human female, seem to have for their office to contain a store of milk, sufficient to supply the immediate wants of the child when it is first applied to the breast; so that it shall not be disappointed, but shall be induced to proceed with sucking, until the *draught* be occasioned (§ 836).

Fig. 163.*



831. The Mammary gland may be detected at an early period of fœtal existence, and it then presents no difference in the male and female; and it continues to grow, in each sex, in proportion to the body at large, up to the period of puberty. At that epoch, however, the gland begins to undergo a special enlargement in the female; and by the age of twenty, it attains its full size previous to lactation. Even then, however, the milk-follicles cannot be injected from the tubes. During pregnancy, the mammary glands receive a greatly-increased quantity of blood. This determination often commences very early; and produces a feeling of tenderness and distention, which is a valuable sign (where it occurs in conjunction with others) of conception having taken-place. The vascularity of the gland continues to increase during pregnancy; and at the time of parturition, its lobulated character can be distinctly felt. The follicles cannot be readily injected, however, until the gland is in a state of complete functional activity; *i.e.*, during lactation.—The Mammary gland of the Male does not undergo this increase of development, except under certain peculiar circumstances to be presently noticed (§ 836); and it remains a sort of miniature picture of that of the female, its diameter varying from that of a large pea to an inch or even two inches.

832. The Milk, secreted by the Mammary glands, consists of Water, holding in solution the peculiar Albuminous substance termed *Casein*, and various Saline ingredients, together with (in most cases) a certain form of Sugar; and having Oleaginous globules suspended in it. These globules are surrounded by a thin albuminous pellicle, which keeps them asunder so long as the milk

* Termination of portion of Milk-duct in follicles, from a mercurial injection by Sir A. Cooper.

remains at rest.—The existence of these elements in ordinary Milk (as that of the Cow) is made apparent by the processes to which it is subjected in domestic economy. If it be allowed to stand for some time, exposed to the air, a large part of the oleaginous globules come to the surface, in consequence of their inferior specific gravity; and thus is formed the *cream*, which includes also a considerable amount of casein, with the sugar and salts of the milk. These may be partly separated by the continued agitation of the cream, as in the process of 'churning;' this, by rupturing the envelopes of the oil-globules, separates it into *butter*, which is formed by their aggregation, and *buttermilk*, containing the casein, sugar, &c. A considerable quantity of casein, however, is still entangled with the oleaginous matter; and this has a tendency to decompose, so as to render the butter rancid. It may be separated by keeping the butter melted at a temperature of 180°, when the casein will fall to the bottom, leaving the butter pure and much less liable to change; an operation which is commonly known as the *clarifying* of butter.—The Milk, after the cream has been removed, still contains the greater part of its casein and sugar. If it be kept long enough, a spontaneous change takes-place in its composition; an incipient decomposition in the casein being the cause of the conversion of the sugar into lactic acid, and this coagulating the casein by precipitating it in small flakes. The same precipitation may be accomplished at any time by the agency of various acids, especially the acetic, which does not act upon albumen; but casein cannot be coagulated, like albumen, by the influence of heat alone (§ 172). The most complete coagulation of casein is effected by the agency of the dried stomach of the calf, known as *rennet;* which exerts so powerful an influence as to coagulate the casein of 1800 times its weight of milk. It is thus that, as in the making of cheese, the *curd* is separated from the *whey;* the former consisting chiefly of the casein, whilst the latter contains a large proportion of the saline and saccharine matter which entered into the original composition of the milk. These may be readily separated by evaporation.

833. The principal characters of Casein have been already stated (§ 172).—The Oleaginous matter consists, like the fats in general, of the two substances, oleine and stearine; but it also contains another substance peculiar to it, which is termed *butyrine*. This last (to which the characteristic smell and taste of butter are due) is converted by saponification into three volatile acids, of strong animal odour, to which the names of butyric, capric, and caproic acids have been given. This change may be effected, at any period, by treating the butyrine with alkalies; but it may also take-place by spontaneous decomposition, which is favoured by time and moderate warmth.—The Sugar of Milk is peculiar as containing nearly 12 per cent. of water; so that it may be considered as really

a *hydrate of sugar*. It is nearly identical in its composition with starch; and may, like it, be converted into true sugar by the agency of sulphuric acid. But it is chiefly remarkable for its proneness to conversion into lactic acid, under the influence of a *ferment* or decomposing azotized substance.—The Saline matter contained in Milk appears to be nearly identical with that of the blood; with a larger proportion, however, of the phosphates of lime and magnesia, which amount to 2 or 2½ parts in 1000. These are held in solution chiefly by the casein, which has a remarkable power of combining with them. The Casein of Human milk is much less readily precipitable, either by acids or by rennet, than is that of the milk of the domesticated Mammals generally; the casein of Ass's milk being that which approaches it most nearly in this respect.

834. Thus ordinary Milk contains the three classes of organic principles which form the chief part of the food of animals,—namely, the albuminous, the saccharine, and the oleaginous; together with the mineral elements which are required for the development and consolidation of the fabric of the infant. It would appear, however, that the combination of all these is not necessary, but that it rather has reference to the composition of the food on which the animal is destined to be afterwards supported. Thus in the Carnivora, the milk contains little or no sugar, which principle is altogether wanting in the food of the adult. Amongst the different species of Herbivorous animals, the proportion of the several ingredients varies considerably; and it is also liable to considerable variation in accordance with the nature of the food, the amount of exercise taken by the animal that affords it, and other circumstances. Thus in the milk of the Cow, Goat, and Sheep, the average proportions of Casein, Butter, and Sugar are nearly the same one with another (casein predominating, however, in the milk of the Cow), each amounting to from 3 to 5 per cent. In the milk of the Ass and Mare, on the other hand, the proportion of Casein is under 2 per cent., the oleaginous constituents are scarcely 1 per cent., whilst the sugar and allied substances rise to 7 or 8 per cent. In the Human female, the saccharine and oleaginous elements predominate, the amount of casein being intermediate between that of Ass's and that of Cow's milk.—The proportion of the saccharine and oleaginous elements in any kind of milk appears to be considerably affected by the amount in which these are present in the food, and by the degree in which the quantity ingested is consumed by the respiratory process. Thus a low external temperature and out-door exercise, by increasing the production of carbonic acid from the lungs, occasion the consumption of the oleaginous and saccharine matters which might otherwise pass into the milk, and thus diminish the amount of cream. On the other hand, exercise favours the secretion of casein; which would seem

to show that this ingredient is derived from the disintegration of the azotized tissues. Thus in Switzerland, the cattle which pasture in exposed situations, and which are obliged to use a great deal of muscular exertion, yield a very small quantity of butter but an unusually-large proportion of cheese; yet the same cattle, when stall-fed, give a large quantity of butter and very little cheese.

835. The Milk first secreted after parturition, known as the *Colostrum*, is very different from ordinary milk; and possesses a strongly purgative action, which is useful in clearing the bowels of the infant from the various secretions which have accumulated in them at birth, constituting the *meconium*. The Colostrum, when examined with the Microscope, is found to contain a multitude of large yellow granulated corpuscles, each of which seems composed of a number of small grains aggregated together; these corpuscles are probably metamorphosed epithelial cells of the mammary ducts. The Colostric character is sometimes retained for some time after birth, and severely affects the health of the infant. This may happen without any peculiarity in the ordinary characters of the secretion, which has all the appearance of healthy milk; but the Microscope at once detects the difference, by the presence of the colostric corpuscles.

836. The formation of this Secretion is influenced by the Nervous system, to a greater degree, perhaps, than that of any other. The process may go-on continuously, to a slight degree, during the whole period of lactation; but it is only in animals which have special reservoirs for the purpose, that any accumulation of the fluid can take-place. In the Human female, as we have seen, these are so minute as to hold but a trifling quantity of milk; and the greater part of the secretion is actually formed whilst the child is at the breast. The irritation of the nipple produced by the act of suction, and the mental emotion connected with it, concur to produce an increased flow of blood into the gland, which is known to nurses as the *draught;* and thus the secretion is for the time greatly augmented. The 'draught' may be produced simply by the emotional state of mind, as by the thought of the child when absent; whilst the irritation of the nipple may alone occasion it; but the two influences usually act simultaneously. The most remarkable examples of the influence of such stimuli on the Mammary secretion, are those in which milk has been produced by girls and old women, and even by men, in quantity sufficient for the support of an infant. The application of the child to the nipple in order to tranquillize it, the irritation produced by its efforts at suction, and the strong desire to furnish milk, seem in the first instance to occasion an augmented nutrition of the gland, so that it becomes fit for the performance of its function; and then to produce in it that state of functional activity, the result of which is the production of Milk.

837. It is not only in this way, however, that the Mammary secretion is influenced by the condition of the mind; for it is peculiarly liable to be affected as to quality, by the habitual state of the feelings, or even by their temporary excitement. Thus a fretful temper not only lessens the quantity of milk, but makes it thin and serous, and gives it an irritating quality; and the same effect will be produced for a time by a fit of anger. Under the influence of grief or anxiety, the secretion is either checked altogether, or it is diminished in amount, and deteriorated in quality. The secretion is usually checked altogether by terror; and it may be so changed in its characters under the influence of violent passion, as to produce the most injurious and even fatal consequences to the infant. So many instances are now on record, in which children, that have been suckled within a few minutes after the mothers have been in a state of violent rage or terror, have died suddenly in convulsive attacks, that the occurrence can scarcely be set down as a mere coincidence; and certain as we are of the deleterious effects of less severe emotions upon the properties of the milk, it does not seem unlikely that, in these cases, the bland nutritious fluid should be converted into a poison of rapid and deadly operation.

838. Of the quantity of Milk ordinarily secreted by a good Nurse, it is impossible to form any definite idea; as the amount which can be artificially drawn, affords no criterion of that which is ordinarily secreted at the time of the 'draught.' The quantity which can be squeezed from either breast at any one time, and which, therefore, must have been contained in its tubes and reservoirs, is about two ounces. The amount secreted will depend upon several circumstances; such as the nature and amount of the ingesta, the state of bodily health, and the condition of the mind. An adequate but not excessive supply of nutritious food, in which the farinaceous, oleaginous, and albuminous principles are duly blended; a vigorous but not plethoric constitution, regular habits, and moderate exercise, together with a cheerful and tranquil temper; altogether produce the most beneficial influence upon the secretion. It is seldom that stimulating liquors, which are so commonly indulged-in, are anything but prejudicial; but the unmeasured condemnation of them in which some writers have indulged, is certainly injudicious; as experience amply demonstrates the improvement in the condition both of mother and infant, which *occasionally* results from the moderate employment of them.—In the administration of medicines to the mother, it is very desirable that the tendency of soluble saline substances to pass into the milk, and thus to affect the child, should be borne in mind. The vegetable substances used in medicine seem to have much less disposition to pass-off by this secretion; and they are consequently to be preferred during lactation, unless it be desired to act on the system of the child as well as on that of the mother.

839. From the close correspondence which exists between the elements of the Milk and those of the Blood, it is evident that we cannot expect to trace the existence of the former, as such, in the circulating current. It is interesting, however, to remark, that a preparation appears to be taking-place in the laboratory of the system, for the production of this secretion, long before the period of parturition. The Urine of pregnant women almost invariably contains a peculiar substance termed *kiestin*, which is nearly related to casein, and which disappears from the urine as soon as lactation has fully commenced. It would seem, therefore, that a compound of this nature is in course of preparation during pregnancy; and that it is eliminated by the kidney, until the Mammary gland is prepared for the active performance of its functions.—That the Kidney may relieve the system from the accumulation of other constituents of the mammary secretion, appears from a recorded case, in which the urine of a parturient female who did not suckle her infant, was found to contain a considerable quantity of butyric acid during several days. There can be no doubt that, in ordinary states of the system, this secretion cannot be required for the depuration of the blood; since it does not occur in the male at all, and is present in the female at particular times only. But these facts afford ground to believe that, when the process is going-on, certain products are generated in the system, which are not found there at other times. And it is quite certain that the sudden checking of the secretion, or the re-absorption of the fluid already poured-out, occasioning an accumulation of these substances in the circulating current, may give-rise to very injurious consequences. Some very curious instances are on record, in which a transference of the secreting power to some other surface has taken-place under such circumstances, so as to relieve the system from the accumulation in question.

CHAPTER XII.

OF THE NERVOUS SYSTEM AND ITS ACTIONS.

1. *General View of the operations, of which the Nervous System is the instrument.*

840. We have now considered the entire series of those operations which make-up the *vegetative* or *organic* life of the Animal; including those functions by which the germ is prepared, by which it is nourished until it can be left to its own powers, by which its

continued development is effected until the fabric characteristic of the adult has been built-up, and by which the normal constitution is maintained through a lengthened period,—so long as the necessary materials are supplied, and no check or hindrance is interposed by external influences to that regular sequence of changes on which the continuance of its powers depends. In this survey it will have been perceived, that the *essential* parts of these operations are, in Animals as in Plants, completely independent of the influence of that which constitutes the peculiar endowment of Animals,—namely, the Nervous System.

a. The *Reduction* of the food in the Stomach, by the solvent power of the gastric fluid, is a purely chemical operation, with which the Nervous System has nothing whatever to do, excepting in so far as it promotes the secretion of the solvent, and stimulates the Muscular coat of the stomach to that peculiar series of contractions, which keeps the contents of the cavity in continual movement, and thus favours the action of the solvent upon them.

b. In the process of *Absorption*, by which the nutritive materials with other substances are introduced into the vessels, the Nervous System has no participation; this being a purely-vegetative operation, partly dependent upon the simple physical conditions which produce Endosmose, and partly on a process of cell-growth.

c. The *Assimilation* of the new material, effected, as we have seen reason to believe, by another set of independent cells, can receive but little influence from the Nervous System, and is obviously capable of taking-place without its aid.

d. The *Circulation* of the Blood, again, though dependent in part upon the impulsive power of a Muscular organ, the Heart, is not on that account brought into closer dependence upon the Nervous System; for we have seen that the contractions of the heart result from its own inherent powers, so as to continue after it has been completely detached from the body; and that the *capillary power*, which is the chief agent in the movement of the blood in the lower animals, and which exerts an important subsidiary action in the higher, is the result of the exercise of certain affinities between the blood and the surrounding tissues, in which the Nervous System can have no immediate concern.

e. The act of *Nutrition*, in which every tissue draws from the circulating blood the materials for its own continued growth and development, and by which it incorporates these with its own substance, essentially consists in a continuance of the same kind of operation as that which takes-place in the early development of the embryo, long anteriorly to the first appearance of the nervous system,—namely, a process of cell-development and metamorphosis, which must be, from its very nature, independent of Nervous agency, though capable of being influenced by it.

f. The same may be said of the *Secreting* operation in general;

for this essentially consists in the separation of certain products from the blood, by cells situated upon free surfaces, which thus remove those products from the interior of the fabric.

g. And the interchange of oxygen and carbonic acid, which takes place between the atmosphere and the venous blood when brought into mutual relation in the lungs, and which is the essential part of the function of *Respiration*, is an operation of a merely physical character, with which the Nervous system can have no direct concern.

h. Finally, the development of the 'sperm-cells' in the one sex, and of the ova containing 'germ-cells' in the other, the subsequent fertilization of the latter by the former, and the changes consequent upon that act, together making-up the function of *Generation*, may be all regarded as modifications of the ordinary Nutritive processes; and are effected, like these, by the inherent powers of the parts concerned in them, at the expense of the materials supplied by the blood, without any direct dependence upon the Nervous system.

841. Still, although the various processes which make-up the *essential* part of the nutritive operations, in Animals as in Plants, are no more dependent on any peculiar influence derived from a Nervous system, in the former, than they are in the latter, it must be evident from the details already given, that there must be in Animals various *accessory* changes, which are requisite for the continuance of the former, and which can only be effected by the peculiar powers with which Animals are endowed.—Thus, to commence with Digestion; this preliminary process, which the nature of the food of the plant renders unnecessary for *its* maintenance, can only be accomplished by the introduction of the food into a cavity or sac, in which it may be submitted to the action of the solvent fluid. The operation of *grasping* and *swallowing* the food, wherever it is performed, is accomplished through the agency of the Nervous system; and if it be checked by the loss of Nervous power, the Digestive process must cease for want of material.—So, again, although the interchange of gaseous ingredients between the atmosphere and the circulating fluid, may take-place with sufficient energy in Plants and the lower Animals through the mere exposure of their general surface to the atmosphere, yet we find that in all the higher Animals certain movements are requisite, for the continual renewal of the air or the water which is in contact with one side of the respiratory surface, and of the blood which is in relation with the other: for the maintenance of these Respiratory movements, a Nervous system is requisite.—In the Excretory processes, moreover, the removal of the effete matters from the body can only be accomplished, in the higher Animals, by certain combined movements; the object of which is, to take-up the products that are separated by the action of the proper secreting cells, and to carry them to the exterior of the body, there to be set-free: and these

combined movements can only be effected by the agency of the Nervous system.—Lastly, in the act of Reproduction, the arrangement of the sexual organs in Animals requires that a certain set of movements should be adapted to bring together the contents of the 'sperm-cells' of the male, and of the 'germ-cells' of the female; and also for the expulsion of the ovum from the body of the latter, in a state of more or less advanced development: for these movements a special arrangement is made, in the construction of the Nervous system, and in the application of its peculiar powers.

842. Thus we see that, although the Organic functions of the Animal are essentially independent of the Nervous System, this system affords the conditions which are requisite for their continued maintenance; being the instrument whereby the muscles are called into action for the performance of those various combined actions, that constitute the *mechanism* (so to speak) by which the Vegetative part of the fabric is combined with the Animal portion of the organism. We are not to suppose, however, that *every* movement which takes-place in the Animal body is dependent upon the Nervous System; for we have seen that the Muscular tissue may be employed to perform contractions excited by stimuli applied to itself, and that it may thus execute a set of movements in which the nervous system has no direct participation. And it is desirable that the Student should observe, that these are, in all instances, those most *directly* connected with the Vegetative functions, and, at the same time, those of the simplest and most straight-forward character.—Thus, the peristaltic movement, by which the alimentary and fæcal matters are propelled along the Intestinal tube, results from the *direct* excitement of the contractility of its muscular walls, and is entirely independent of Nervous agency; and this movement is accomplished by the successive contraction of the different fasciculi surrounding the tube, which take-up (as it were) each other's action (§ 352). So, again, the successive contractions and dilatations of the cavities of the Heart, which perform so important a part in the Circulation of the blood, are the result of the properties inherent in that organ; the muscular fibres of which are excited to a peculiar rhythmical and consentaneous contraction, by the flow of blood into the cavities when dilating. Moreover, in the Excretory ducts of various glands, we find a Muscular coat, by which the fluids secreted in the glands are propelled towards their outlet on the exterior of the body, or on one of its free internal surfaces.

843. In these instances, then, we observe that the simple Contractility of Muscular structure, excited by *direct* stimulation, is applied to effect the movements most closely connected with the Organic functions. With the processes, therefore, which take place in the *penetralia* of the system, the Nervous System has no direct concern. Its office is to guard the *portals* for entrance and exit, to fill those chambers which admit the new materials from the

external world, or to empty the receptacles which collect from the interior of the system the effete matters that are to be cast-out from it. And we find that, for these offices, the Nervous system is employed in its very simplest mode of operation;—that which does not involve Sensation, Intelligence, Will, or even Instinct (in the proper sense of that term), but which may take place independently of all consciousness,—by the simple *reflexion* of an impression, conveyed *to* a ganglionic centre by one set of fibres proceeding towards it from the circumference, along another set which passes *from* it to the muscles and calls them into operation (§ 394). This 'reflex function,' therefore, is the simplest application of the Nervous System in the Animal body. We shall presently see reason to believe, that a very large proportion of the movements of many of the lower animals are of this reflex character; and that they are not necessarily accompanied by sensation, although this may usually be aroused by the same cause which produces them. As we rise, however, in the scale of Animal existence, we find the reflex movements forming a smaller and smaller proportion of the whole; until, in Man, they constitute so limited a part of the entire series of movements of which the Nervous system is the agent, that their very existence has been overlooked.

844. But the main purpose of the Nervous System is to serve as the instrument of those *Psychical** powers, which are the distinguishing attribute of the Animal. It has been already pointed-out, that the possession of *consciousness* (or of the capability of receiving sensations), and the power of executing spontaneous movements (that is, movements which are not immediately dependent upon external stimuli), constitute the essential features in which the Animal differs from the Plant. All the other differences in structure that respectively characterize these two classes of living beings, are subordinate to this one leading distinction,—the presence of a Nervous system and of its peculiar attributes in the one,—and its absence in the other. Now when we attempt to analyze these peculiar attributes, we may resolve them, like the properties of the material body, into different groups. We find that the *first* excitement of all mental changes, whether these involve the action of the *feelings* or of the *reason*, depends upon *sensations;* which are produced by impressions made upon the nerves of certain parts of the body, and are conveyed by these to a particular ganglionic centre, which is termed the *sensorium*,—being the part in which Sensation, or the capability of *feeling* external impressions, especially resides.

845. Now there are numerous actions, especially among the lower Animals, which seem to be as far removed from the influence of the Will, and as little directed by Intelligence, as the 'reflex' move-

* This term, derived from the Greek ψυχη, is used to designate the sensorial and mental endowments of Animals, in the most comprehensive acceptation of those terms.

ments themselves; but which, nevertheless, depend upon sensation for their excitement. The sensation may *immediately* direct the movement, and may call the muscular apparatus into action in such a manner, as—without any calculation of consequences, any intentional adaptation of means to ends, any exertion of the reason, or any employment of a discriminating Will—to produce an action, or train of actions, as directly and obviously adapted to the well-being of the individual, as we have seen those of the reflex character to be. Of this we have an excellent example in the act of Sneezing; the purpose of which is obviously to expel from the nasal passages those irritating matters, the sense of whose presence excites the complicated assemblage of muscular movements concerned in the operation. This class of actions may be appropriately termed *Sensori-motor* or *Consensual;* and under it we may include most of those purely *instinctive* actions of the lower animals, which, being prompted by sensations, cannot be assigned to the reflex group. These seem to make-up, with the reflex, nearly the whole of the Animal functions in many tribes (§ 860); but they are found to be gradually brought under the domination of the Intelligence and Will, as we rise towards Man, in whom those faculties are most strongly developed, so as to keep the Consensual as well as the Reflex actions quite in subordination to the more elevated purposes of his existence.—Closely allied, however, to these, are the purely *Emotional* movements; in which the sensation excites a mental feeling or impulse, that reacts upon the muscular system without giving rise to any distinct *idea*, and consequently without having called the intellect and will into exercise. In fact, these emotional movements are often performed in opposition to the strongest efforts of the will to restrain them; as when laughter is provoked by some ludicrous sight or sound, or by the remembrance of such, at an unseasonable time. It is probable, from the strong manifestations of emotion exhibited by many of the lower animals, that some of the actions which we assemble under the general designation of instinctive, are to be referred to this group.

846. There are many sensations, however, which do not thus immediately give-rise to muscular movements; their operation being rather that of stimulating to action the Intellectual powers. There can be little doubt that *all* Mental processes are dependent in the first instance upon Sensations, which serve to the Mind the same kind of purpose that food and air fulfil in the economy of the body. If we could imagine a being to come into the world with its mental faculties fully prepared for action, but destitute of any power of receiving sensations, these faculties would never be aroused from the condition in which they are in profound sleep; and the being must remain in a state of complete unconsciousness, because there is nothing of which it can be made conscious, no kind of *idea* which can be aroused within it. But after the mind has once been in

active operation, the destruction of all *future* power of receiving sensations would not reduce it again to the inactive condition. For sensations are so stored-up in the mind by the power of Memory, that they may give-rise to ideas at any future time; and thus the mind may feed (as it were) upon the *past*. Now the ideas which are excited by sensations, and which are coloured by the state of feeling which accompanies them, become the subjects of Reasoning processes more or less complex, sometimes of the utmost brevity and simplicity, sometimes of the most refined and intricate nature. These reasoning processes may result in an impulse to perform a particular action, which, in so far as it is the expression of a definite *purpose* or *designed* adaptation of means to ends on the part of the performer, instead of being the result of a mere blind indiscriminating impulse, is to be accounted an act of *Intelligence*. In the execution of such a purpose, however, the Will is not necessarily called into action; for *ideas*, like sensations, may automatically call-forth movements, as we see them do in the states of Reverie, Somnambulism, &c., in which the Will is temporarily in abeyance. Such movements may be appropriately designated *Ideo-motor*. It is probable that those intelligent actions which many of the lower animals (the Dog, Horse, Elephant, &c.) are undoubtedly capable of performing, are to be referred to this category; since we have no reason to believe that any such beings possess that power of directing and controlling the current of thought and feeling, which gives to the Will of Man the power of keeping in check the automatic impulses of his mind as well as those of his body, or of utilizing them to its own purposes. The *Volitional* movements, which are the direct results of the exertion of the Will, constitute the highest form of the action of the Nervous System; since these are the expressions of a power which is beyond and above all that can be accounted a mere automatic mechanism, responding in fixed and determinate modes to external impressions.

847. Thus, then, we have to consider the Nervous system under five heads;—*first*, as the instrument of the Reflex actions;—*second*, as the instrument of the Consensual actions;—*third*, as the instrument of the Emotional actions;—*fourth*, as the instrument of the Intellectual processes, which may express themselves in Ideo-motor actions;—and *fifth*, as the instrument of Volitional movements. There is reason to believe that the Nervous Centre from which the muscles derive their impulse to contract, is the same, whether the movement be prompted by an *impression* which does not excite the consciousness, by a *sensation*, by an *emotion*, by an *idea*, or by a *volition;* and that this instrument may be played-upon (so to speak) by other centres, which minister to these functions respectively.—In order that the relations of the component parts of the Nervous apparatus may be better understood, it will be desirable to take a brief survey of its comparative structure in the principal

groups of Animals; and to inquire what actions may be justly attributed to its several divisions in each instance: commencing with those in which the structure is the simplest, and the variety of actions the smallest; and passing-on gradually to those in which the structure is increased in complexity by the addition of new and distinct parts, and in which the actions present a corresponding variety.

2. *Comparative Structure and Actions of the Nervous System.*

848. From what has been already said (§ 373–9) of the characters of the two elementary forms of the Nervous Tissue, it is evident that no Nervous System can exist, in which both these forms should not be present. We look, therefore, for *ganglia*, composed of the *vesicular* nervous substance, and serving as the centres of nervous power; and for cords or *trunks*, composed of the *tubular* substance, and serving to communicate between the ganglia and the parts with which they are to be functionally connected. Now it is quite certain that, at present, no such Nervous apparatus can be detected in many of the lowest Animals; and some Physiologists have had recourse to the supposition of their possessing a 'diffused' nervous system,—that is, of their possessing nervous particles, in a separate form, incorporated (as it were) with their tissues. But we have seen that each tissue possesses its own properties, and can perform its own actions independently of the rest;—that even the contractility of Muscular fibre is by no means dependent upon the Nervous system, though usually called into play through its means;—and that the simplest office of a Nervous System is to produce a muscular movement in respondence to a certain impression; which action requires that it should have an *internuncial* or communicating power, only to be exercised (so far as we at present know) by continuous fibres. The apparent absence of a Nervous system is doubtless to be attributed in many instances, to the general softness of the tissues of the body, which prevents it from being clearly made-out among them. And it is to be remembered, that, on the principles already stated, we should expect to find it bearing a much smaller proportion to the entire structure, in these lowest Animals whose functions are chiefly Vegetative, than in the highest, in which the vegetative functions seem destined merely for the development and subsequent maintenance of the Nervous and Muscular systems.

849. Among the *Radiated* classes, the parts of whose bodies are arranged in a circular manner around the mouth, and repeat each other more or less precisely, the Nervous system presents a corresponding disposition. In the Star-fish, for example, which is one of the highest of these animals, it forms a ring which surrounds the mouth; this ring consists of nervous cords, which form communica-

tions between the several ganglia, one of which is placed at the base of each ray. The number of these ganglia corresponds with that of the rays or arms; being *five* in the common Star-fish; and from *nine* to *fifteen*, in the species possessing those several numbers of members. The ganglia appear to be all similar to each other in function, as they are in the distribution of their branches; every one of them sending a large trunk along its own ray, and two small filaments to the organs in the central disk. The rays being all so similar in structure as to be exact repetitions of each other, it would appear that none of the ganglia can have any controlling power over the rest. All the rays (in certain species) have at their extremities what seem to be very imperfect eyes; and so far as these can aid in directing the movements of the animal, it is obvious that they will do so towards all sides alike. Hence there is no one part which corresponds to the *head* of higher animals; and the ganglia of the nervous system, like the parts they supply, are but repetitions of one another, and are capable of acting quite independently. Each would perform its own individual functions if separated from the rest; but, in the entire animal, their actions are all connected with each other by the circular cord, which passes from every one of the five ganglia to those on either side of it. We shall find that, in Articulated and Vertebrated animals, there is a similar repetition of corresponding ganglia on the two sides of the median plane of the body; and that these are connected by *transverse* bands, analogous in function to the circular cord of the Star-fish. Moreover, we shall see a like repetition of ganglia, almost or precisely similar in function, in passing from one extremity of these animals to the other; and these ganglia are connected by longitudinal cords, whose function is in like manner *commissural*.—From the best judgment we can form of the actions of the Star-fish, by comparing them with the corresponding actions of higher animals, we may fairly regard the greater number of them as simply *reflex;* being performed in direct respondence to external stimuli, the impression made by which is propagated to one or more of the ganglia, and excites in them a motor impulse. How far the movements of these animals are indicative of *sensation*, we have not the power of determining; but it may be safely affirmed that they afford no indication of the exercise either of reasoning faculties or of voluntary power.

850. Perhaps the simplest form of a Nervous system is that presented by certain of the lower *Mollusca;* for the body not here possessing any repetition of similar parts, the nervous system is destitute of that multiplication of ganglia which we see in the Star-fish; whilst the limited nature of the animal powers involves a corresponding simplicity in the integral parts of their instrument. The animals to which reference is here made, form the class *Tunicata*, which is intermediate, in many respects, between the

ordinary Mollusks and the Zoophytes. They consist essentially of an external membranous bag or tunic, within which is a muscular envelope, and again within this a respiratory sac, which may be considered as the dilated pharynx of the animal. At the bottom of this last, is the entrance to the stomach; which, with the other viscera, lies at the lower end of the muscular sac. The external envelopes have two orifices; a mouth, to admit water into the pharyngeal sac; and an anal orifice, for the expulsion of the water which has served for respiration, and of that which has passed through the alimentary canal, together with the fæcal matter, the ova, &c. A current of water is continually being drawn into the pharyngeal sac, by the action of the cilia that line it; and of this, a part is driven into the stomach, conveying to it the necessary supply of aliment in a very finely divided state; whilst a part is destined merely for the aeration of the circulating fluid, and is transmitted more directly to the anal orifice, after having served that purpose. These animals are for the most part fixed to one spot, during all save the earliest period of their existence; and they give but little external manifestation of life, beyond the continual entrance and exit of the currents already adverted-to, which, being effected by ciliary action, are altogether independent of the nervous system (§ 234). When any substance is drawn-in by the current, however, the entrance of which would be injurious, it excites a general contraction of the mantle or muscular envelope; and this causes a jet of water to issue from one or both orifices, which carries the offending body to a distance. And, in the same manner, if the exterior of the body be touched, the mantle suddenly and violently contracts, and expels the contents of the sac.

851. These are the only actions, so far as we know, which the Nervous system of these animals is destined to perform. They scarcely exhibit a trace of eyes, or of other organs of special sense; and the only parts that appear peculiarly sensitive, are the small 'tentacula' or feelers that guard the oral orifice. Between the two apertures in the mantle, we find a solitary ganglion, which receives branches from both orifices, and sends others over the muscular sac. This, so far as we know at present, constitutes the whole nervous system of the animal; and it is fully sufficient to account for the movements which have been described. For the impression produced by the contact of any hard substance with the tentacula, or with the general surface of the mantle, being conveyed by the *afferent* fibres of this ganglion, will excite in it a reflex motor impulse; which, being transmitted to the muscular fibres of the contractile sac, as well as to those circular bands that surround the orifices and act as *sphincters*, will call-forth the movements in question.

852. In the *Conchifera*, or Mollusks inhabiting 'bivalve' shells, there are invariably two ganglia, having different functions. The

larger of these (Plate II., Fig. 1, *c*), corresponding to the single ganglion of the Tunicata, is situated towards the posterior end of the body (that is, the end most distant from the mouth), in the neighbourhood of the posterior muscle that draws the valves together; and its branches are distributed to that muscle, to the mantle, to the gills (*d*, *d*), and to the siphons (*e*, *e*) by which the water is introduced and carried-off. But we find another ganglion, or rather pair of ganglia (*a*, *a*), situated near the front of the body, either upon the œsophagus, or at its sides; these ganglia are connected with the very sensitive tentacula which guard the mouth; and they may be regarded as presenting the first approach, both in position and functions, to the brain of higher animals. In the *Oyster* and others of the lower Conchifera which have no foot, these are the only principal ganglia; but in those having a foot, which is a muscular tongue-like organ, we find an additional ganglion (*b*) connected with it. This is the case in the *Solen* or animal of the 'razor-shell;' whose foot is a very powerful boring-instrument, enabling it to penetrate deeply into the sand.—Here, then, we have three distinct kinds of ganglionic centres; every one of which may be doubled, or repeated on the two sides of the body. *First*, the *cephalic* ganglia (*a*, *a*), which are probably the sole instruments of *sensation* and of the *consensual* movements; these are almost invariably double, being connected together by a transverse band, which arches over the œsophagus. *Second*, the *pedal* ganglion (*b*), which is usually single, in conformity with the single character of the organ it supplies; but in one very rare Bivalve Mollusk, the foot is double, and the pedal ganglion is double also. *Third*, the *respiratory* ganglion (*c*), which frequently presents a form that indicates a partial division into two halves, corresponding with the repetition of the organs it supplies on the two sides of the body. Besides these principal centres, we meet with numerous smaller ones upon the nervous cords (*f*, *f*, *g*, *g*), which proceed from them to the different parts of the general muscular envelope or mantle.

853. Now it will be observed, that the two cephalic ganglia (*a*, *a*) are connected with the pedal ganglion (*b*) by means of a pair of trunks proceeding from the former to the latter; and that they are, in like manner, separately connected with the respiratory or branchial ganglion (*c*). There is good reason to believe, that the *pedal* and *branchial* ganglia minister to the purely *reflex* actions of the organs they respectively supply, and that they would serve this purpose as well, if altogether cut-off from connection with the cephalic ganglia; whilst the *cephalic*, being the instruments of the actions which are called-forth by sensation, exert a general control and direction over the movements of the animal, through the medium of the trunks by which they communicate with the ganglia in immediate connection with the muscular apparatus. It is difficult, however, to make satisfactory experiments upon this subject

in these animals, their movements being for the most part slow and feeble, and their nervous system not readily accessible; and our idea of the respective functions of their ganglia is chiefly founded upon the distribution of their nerves, and upon the analogous operations of the ganglia that correspond to them in other animals.

854. In ascending through the Molluscous series, we find the Nervous system increasing in complexity, in accordance with the general organization of the body; the addition of new organs of special sensation, and of new parts to be moved by muscles, involving the addition of new ganglionic centres, whose functions are respectively adapted to these purposes. But we find no other multiplication of *similar* centres, than a doubling on the two sides of the body; excepting in a few cases, where the organs they supply are correspondingly multiplied. Of this we have a very characteristic example in the arms of the Cuttle-fish, which are furnished with great numbers of contractile suckers, every one possessing a ganglion of its own. Here we can trace very clearly the distinction between the *reflex* actions of each individual sucker, depending upon the powers of its own ganglion; and the movement prompted by sensation, which results from its connection with the cephalic ganglia. The nervous trunk which proceeds to each arm, may be distinctly divided into two tracts; in one of which are contained the ganglia which peculiarly appertain to the suckers, and which are connected with them by distinct filaments; whilst in the other there is nothing but tubular structure, forming a direct communication between these and the cephalic ganglia; so that each sucker has a separate relation with a ganglion of its own, whilst all are alike connected with the cephalic ganglia, and are placed under their control. We see the results of this arrangement, in the mode in which the contractile power of the suckers may be called into operation. When the animal embraces any substance with its arm (being directed to this action by its sight or other sensation), it can bring all the suckers simultaneously to bear upon it; evidently by a voluntary or instinctive impulse, transmitted along the connecting cords that proceed from the cephalic ganglia to the ganglia of the suckers. On the other hand, any individual sucker may be made to contract and attach itself, by placing a substance in contact with it alone; and this action will take-place equally well when the arm is separated from the body, or even in a small piece of the arm when recently severed from the rest,—thus proving that, when it is directly excited by an impression made upon itself, it is a *reflex* act, quite independent of the cephalic ganglia, not involving sensation, and taking-place through the medium of its own ganglion alone.

855. In the Molluscous classes, generally speaking, the Nervous system bears but a small proportion to the whole mass of the body; and the part of it which ministers to the *general* movements of the

fabric, is often small in proportion to those which serve some *special* purpose, such as the actions of respiration. This is what we should expect from the general inertness of their character, and from the small amount of muscular structure which they possess.—On the other hand, in the *Articulated* classes, in which the locomotive apparatus is highly developed, and its actions of the most energetic kind, we find the nervous system almost entirely subservient to this function. In its usual form, it consists of a chain of ganglia, connected by a double cord; commencing in the head, and passing backwards through the body (Plate II., Fig. 2). The ganglia, though they usually appear single, are really double; being composed of two equal halves, sometimes closely united on the median line, but occasionally remaining separate, like the cephalic ganglia of the Solen (Fig. 1, *a*, *a*), and being united together by a transverse commissural trunk. In like manner, the longitudinal cord, though really double (as seen in the upper part of Fig. 2), often appears to be single, in consequence of the close approximation of its lateral halves (as in the lower part of Fig. 2). In general we find a ganglion in each segment, giving-off nerves to the muscles of the legs, as in Insects, Centipedes, &c.; or to the muscles that move the rings of the body, where no extremities are developed, as in the Leech, Worm, &c. In the lower vermiform (or Worm-like) tribes, especially in the marine species, the number of segments is frequently very great, amounting even to several hundreds; and the number of ganglia follows the same proportion. Whatever be their degree of multiplication, they seem but repetitions of one another; the functions of each segment being the same with those of the rest. The *cephalic* ganglia, however, are always larger and more important; they are connected with the organs of special sense; and they evidently possess a power of directing and controlling the movements of the entire body, whilst the power of each ganglion of the trunk is confined to its own segment.—The longitudinal ganglionic cord of Articulata occupies a position which seems at first sight altogether different from that of the nervous system of Vertebrated animals; being found in the neighbourhood of the *ventral* or inferior surface of their bodies, instead of lying just beneath their dorsal or upper surface. There is reason, however, for regarding the *whole* of the body of these animals as having an inverted position; so that they may be considered as really crawling upon their backs. On this view, their longitudinal nervous tract corresponds with the spinal cord of Vertebrata in *position*, as we shall find that it does in *function*.

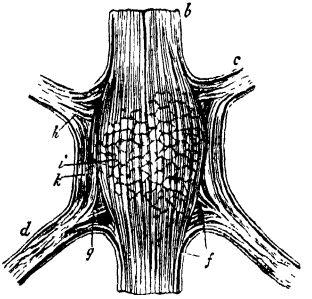
856. We shall draw our chief illustrations of the structure of the nervous system in the Articulated series, from the class of *Insects*, in which it has been particularly examined. In these animals, the number of segments never exceeds twelve (exclusive of the head), either in their larva, pupa, or imago state; and the total number of

pairs of ganglia, therefore, never exceeds thirteen, including the cephalic ganglia. These, in the larva, are nearly equal in size, one to another (Plate II., Fig. 2, *a*, and 1—12); the functions of the different segments of the body being almost uniform; and the development of the organs of special sense not being such as to involve any considerable predominance in the size of the cephalic ganglia. We observe at the anterior extremity the pair of cephalic ganglia (*a*), from which proceeds, on each side, a cord of communication to the first ganglion (1) of the trunk. This double cord, with the ganglia above and below, thus forms a ring which embraces the œsophagus; the cephalic ganglia being situated on the upper side of it, whilst the ganglionic column of the trunk lies beneath the alimentary canal along its whole length. In the *Sphinx ligustri*, or Privet Hawk-moth, the nervous system of whose larva is here represented, the last two segments of the body are drawn-together, as it were, into one; and instead of distinct 11th and 12th ganglia, we find but a single mass nearly double the size of the rest, and obviously formed of the elements that would have otherwise gone to form the two.

857. When the structure of the chain of ganglia is more particularly inquired-into, it is found to consist of two distinct *tracts;* one of which is composed of nervous fibres only, and passes backwards from the cephalic ganglia, over the surface of all the ganglia of the trunk; whilst the other includes the ganglia themselves. Hence every part of the body has two sets of nervous connections; a direct one with the ganglion of its own segment, and an indirect with the cephalic ganglia. Impressions made upon the afferent fibres which proceed from any part of the body to the cephalic ganglia, become *sensations* when conveyed to the latter; whilst, in respondence to these, the influence of sensations received by the cephalic ganglia, and operating through them, harmonizes and directs the general movements of the body, by means of the communicating cords proceeding from them. For the *reflex* operations, on the other hand, the ganglia of the ventral cord are sufficient; each one ministering to the actions of its own segment, and, to a certain extent also, to those of other segments. It has been ascertained by the careful dissections of Mr. Newport, that of the fibres constituting the roots by which the nerves are implanted in the ganglia, some pass into the vesicular matter of the ganglion, and, after coming into relation with its vesicular substance, pass-out again on the same side (Fig. 164, *f*, *k*); whilst a second set, after traversing the vesicular matter, passes-out by the trunks proceeding from the opposite side of the same ganglion; and a third set runs along the portion of the cord (*b*) which connects the ganglia of different segments, and enters the nervous trunks that issue from them, at a distance of one or more ganglia above or below. Thus it appears, that an impression conveyed by an afferent fibre to any ganglion, may excite a motion in

the muscles of the same side of its own segment, or in those of the opposite side, or in those of segments at a greater or less distance, according to the point at which the efferent fibres leave the cord.

Fig. 164.*



858. The general conformation of Articulated animals, and the arrangement of the parts of their nervous system, render them peculiarly favourable subjects for the study of the *reflex* actions; some of the principal phenomena of which will now be described. If the head of a Centipede be cut-off, whilst it is in motion, the body will continue to move onwards by the action of its legs; and the same will take place in the separate parts, if the body be divided into several distinct portions. After these actions have come to an end, they may be excited again, by irritating any part of the nervous centres, or the cut extremity of the nervous cord. The body is moved forwards by the regular and successive action of the legs, as in the natural state; but its movements are always forwards never backwards, and are only directed to one side when the forward movement is checked by an interposed obstacle. Hence although they might *seem* to indicate consciousness and a guiding will, they do not so in reality; for they are carried-on, as it were, mechanically; and show no direction of object, no avoidance of danger. If the body be opposed in its progress by an obstacle of not more than half of its own height, it mounts over it, and moves directly onwards, as in its natural state; but if the obstacle be equal to its own height, its progress is arrested, and the cut extremity of the body remains forced-up against the opposing sub-

* Portion of the ganglionic tract of *Polydesmus maculatus*:—*b*, inter-ganglionic cord; *c*, anterior nerves; *d*, posterior nerves; *f*, *k*, fibres of reflex action; *g*, *h*, commissural fibres; *i*, longitudinal fibres, softened and enlarged as they pass through ganglionic matter.

stance, *the legs still continuing to move.*—If, again, the nervous cord of a Centipede be divided in the middle of the trunk, so that the hinder legs are cut-off from connection with the cephalic ganglia, they will continue to move, but not in harmony with those of the fore part of the body; being completely paralysed, as far as the animal's controlling power is concerned, though still capable of performing reflex movements by the influence of their own ganglia, which may thus continue to propel the body in opposition to the determinations of the animal itself.—The case is still more remarkable, when the nervous cord is not merely divided, but a portion of it is entirely removed from the middle of the trunk; for the anterior legs still remain obedient to the animal's control; the legs of the segments, from which the nervous cord has been removed, are altogether motionless; whilst those of the posterior segments continue to act, through the reflex powers of their own ganglia, in a manner which shows that the animal has no power of checking or directing them.

859. The stimulus to the reflex movements of the legs, in the foregoing cases, appears to be given by the contact of the extremities with the solid surface on which they rest. In other cases, the appropriate impression can only be made by the contact of liquid; thus a Dytiscus (a kind of water-beetle) having had its cephalic ganglia removed, remained motionless so long as it rested upon a dry surface; but when cast into water, it executed the usual swimming motions with great energy and rapidity, striking all its comrades to one side by its violence, and persisting in these for more than half an hour. Other movements, again, may be excited through the respiratory surface. Thus, if the head of a Centipede be cut-off, and, while the trunk remains at rest, some irritating vapour (such as that of ammonia or muriatic acid) be caused to enter the air-tubes on one side of it, the body will be immediately bent in the opposite direction, so as to withdraw itself as much as possible from the influence of the vapour; if the same irritation be then applied on the other side, the reverse movement will take place; and the body may be caused to bend in two or three different curves, by bringing the irritating vapour into the neighbourhood of different parts of either side. This movement is evidently a reflex one, and serves to withdraw the entrances of the air-tubes from the source of irritation; in the same manner as the acts of coughing and sneezing in the higher animals, cause the expulsion, from their air-passages, of solid, liquid, or gaseous irritating matters, which may have found their way into them.

860. From these and similar facts it appears, that the ordinary movements of the legs and wings of Articulated animals are of a reflex nature, and may be effected solely through the ganglia with which these organs are severally connected; whilst in the perfect being, they are harmonized, controlled, and directed by the instinctive guidance, which depends upon sensations acting through the

cephalic ganglia and the fibres proceeding from them. There is strong reason to believe, that the operations to which these ganglia are subservient are almost entirely of a *consensual* nature; being immediately prompted by sensations, chiefly those of sight, and seldom involving any processes of a truly rational character. When we attentively consider the habits of these animals, we find that their actions, though evidently directed to the attainment of certain ends, are very far from being of the same spontaneous nature, or from possessing the same *designed* adaptation of means to ends, as those performed by ourselves, or by the more intelligent Vertebrata, under like circumstances. We judge of this by their unvarying character, the different individuals of the same species executing precisely the same movements when the circumstances are the same; and by the very elaborate nature of the mental operations which would be required, in many instances, to arrive at the same results by an effort of reason. Of such we cannot have a more remarkable example, than is to be found in the operations of Bees, Wasps, and other social Insects; which construct habitations for themselves, upon a plan which the most enlightened human intelligence, working according to the most refined geometrical principles, could not surpass; but which yet do so without education communicated by their parents, or progressive attempts of their own, and with no trace of hesitation, confusion, or interruption,—the different individuals of a community all labouring effectively for one common purpose, because their instinctive or consensual impulses are the same.

861. It is interesting to remark, that in the change from the Larva to the perfect or Imago state of the Insect, the Cephalic ganglia undergo a great increase in size (Plate II., Fig. 3, *a*, *a*). This evidently has reference to the increased development of the organs of special sense in the latter; the eyes being much more perfectly formed; antennæ and other appendages used for feeling being evolved; and rudimentary organs of hearing and smell being added. In respondence to the new sensations which the animal must thus acquire, a great number of new instinctive actions are manifested; indeed it may be said that the instincts of the perfect Insect have frequently nothing in common with those of the Larva. The latter have reference to the acquirement of food; the former chiefly relate to the acts of reproduction, and to the provisions requisite for the deposit and protection of the eggs and for the early nutrition of the young.—We find another important change in the nervous system of the adult or perfect Insect; namely, the concentration of the ganglionic matter of the ventral cord in the thoracic region (*e*, *f*); with the three segments of which, the three pairs of legs and the two pairs of wings are connected. The nine segments of the abdomen, in the perfect Insect, give attachment to no organs of motion, and are seldom themselves very moveable; and we find

that the ganglia which correspond with them have undergone no increase in size, but have rather diminished, and have sometimes almost completely disappeared. Where the last segment, however, is furnished with a particularly moveable appendage, such as a sting or an ovipositor, we always find a large ganglion in connection with it.

862. These ganglia of the ventral cord evidently correspond in function with the *pedal* ganglion of the Mollusca; being so many repetitions of it, in accordance with the number of members. We have now to speak of a system of *respiratory* ganglia, which also are repeated in like manner, in accordance with the condition of the respiratory apparatus; this being diffused through the whole body in most of the Articulata, instead of being restricted to one spot as in the Mollusca. The system of respiratory nerves consists of a chain of minute ganglia, lying upon the larger cord, and sending-off its delicate nerves between those that proceed from the ganglia of the latter, as shown in Plate II., Fig. 2. These respiratory ganglia and their nerves are best seen in the thoracic portion of the cord, where the cords of communication between the pedal ganglia diverge or separate from one another. And this is particularly the case in the Pupa state, when the whole cord is being shortened, and their divergence is increased. The thoracic portion of the cord, in the Pupa of the Sphinx ligustri, is shown in Fig. 4; where *a*, *b*, and *c*, represent the 2nd, 3rd, and 4th double ganglia of the ventral cord; *d*, *d*, the cords of connection between them, here widely diverging laterally; and *e*, *e*, the small respiratory ganglia, which are connected with each other by delicate filaments that pass over the ganglia of the ventral cord, and which send-off lateral branches that are distributed to the air-tubes and other parts of the respiratory apparatus, communicating with those of the other system.

863. Besides the Respiratory system of ganglia and nerves, there is in Insects, as in some Mollusks, a set of minute ganglia which is especially connected with the acts of mastication and swallowing; its filaments being distributed to the muscles of the mouth and pharynx, and some of its ganglia being even found on the stomach, where that organ is remarkable for its muscular powers. The number and arrangement of these ganglia vary considerably in different animals, even in those of the same group; but some traces of this distinct system, which is designated as the *stomato-gastric*, may always be found. One of the minute ganglia appertaining to it, and forming its anterior termination, is seen to lie on the median line in front of the great cephalic ganglia (Plate II., Fig. 3, *c*). From this a trunk passes backwards along the œsophagus; which may be likened to the œsophageal branches of the Par vagum in Vertebrata. Two other small ganglia communicating with this, are seen at *d*, *d*.

864. We are not without traces, moreover, among Invertebrated animals, of the *Sympathetic* system of the higher classes; though it is quite a mistake to compare the *entire* system of nerves and ganglia in the former, with the Sympathetic system of the latter, as was formerly done. The chief distribution of the branches of the Sympathetic of Vertebrata, is upon the walls of the blood-vessels, and upon the muscular substance of the heart and alimentary canal; and it is by the passage of some of the filaments, from the system of minute ganglia just pointed-out, to the dorsal vessel, that we recognize it as combining the functions of the Sympathetic with those of the gastric and cardiac portions of the Par vagum. It will be remembered that there is a frequent inosculation between these two nerves, even in the highest animals.

865. Thus we have seen that, in Invertebrated animals, the Nervous System consists of a series of isolated ganglia, connected together by fibrous trunks. The number of these ganglia, and the variety of their function, entirely depend upon the number and variety of the organs to be supplied. In the lowest Mollusca, the regulation of the ingress and egress of water seems almost the only function to be performed; and here we have but a single ganglion. In the Star-fish, we have five or more ganglia; but they are all repetitions one of another, and are obviously the centres of action to the several segments to which they respectively belong, neither having a predominance over the rest. And in the higher Mollusca and Articulata, we have a ganglion, or more commonly a pair of ganglia, situated at the anterior extremity of the body, connected with the organs of special sensation, and evidently exerting a dominant influence over the rest. In the lower Mollusca, we have but a single ganglion for general locomotion; but this is doubled laterally and repeated longitudinally in the Articulata, in accordance with the multiplication of their locomotive organs, so as to form the ventral cord. In like manner, the Mollusca possess a single ganglionic centre for the respiratory movements; and this is repeated in every segment of the Articulata, forming a chain of respiratory ganglia, which regulates the actions of the extensively diffused respiratory apparatus of these animals. The acts of mastication and deglutition, again, in both sub-kingdoms, are immediately dependent upon a distinct set of ganglionic centres; which are connected, however, like the preceding, with the cephalic ganglia. And we have further seen that wherever special organs are developed, whose operations depend upon muscular contraction, ganglionic centres are developed in immediate relation with them; so as to enable them to act by their simple reflex power, as well as under the direction of the cephalic ganglia, as is the case with the suckers of the Cuttle-fish.—Now when we inquire into the relation of the *cephalic ganglia* of Invertebrata to the Brain of the higher Vertebrated animals, we find that these organs cannot be compared in

their totality; for the former are the representatives of a certain portion only, and that usually but a small one, of the latter. The cephalic ganglia of the Centipede, for example, receive nerve-trunks from the eyes, the antennæ, and other sensory organs, and give-off motor nerves to the different moveable parts of the head; and the history of their development, which has been studied by Mr. Newport, shows that they may be considered as the coalesced ganglia of the four segments of which the anterior part of the head is composed; while the first sub-œsophageal ganglia are formed by the coalescence of the four segments entering into the composition of the posterior part of the head. The increased bulk of the cephalic ganglia in the higher Articulata, and especially in the perfect Insect, is obviously for the most part dependent upon the increased development of the visual apparatus, for we find it everywhere proportional to this; and hence we may look upon them as mainly *optic* ganglia, serving to direct the actions of the animal through the sense of sight.—There is no part of these organs which can be considered as *superadded* to the ganglionic masses which are the immediate centres of the cephalic nerves; consequently there is nothing which can be certainly likened either to the Cerebrum or to the Cerebellum of Vertebrata. And the representative of these cephalic ganglia in the Vertebrated Encephalon, is that series of ganglionic centres at the base of the brain, which constitute (as we shall presently find) its fundamental portion, and with which all the cephalic nerves are immediately connected.

866. When we direct our attention to the Nervous system of the Vertebrated series, we perceive that it differs from that of the Invertebrated classes we have been considering, in two remarkable features.—In these last, it has seemed but as a mere appendage to the rest of the system, designed to bring its several parts into more advantageous relation. On the other hand, in the Vertebrata, the whole structure appears subservient to it, and designed but to carry its purposes into operation.—Again, in the Invertebrata, we do not find any special adaptation of the organs of support for the protection of the Nervous System; for it is either inclosed with the other soft parts of the body in one general hard tegument, as in the Star-fish and other Echinodermata, and in Insects, Crustacea, and other Articulata; or it receives a still more imperfect protection, or even none at all, as in the Mollusca. Now in the Vertebrata, we find a special and complex bony apparatus, adapted in the most perfect manner for the protection of the Nervous system; and it is, in fact, the possession of a jointed spinal column, and of its cranial expansion, which best characterizes the group.

867. The Nervous System of Vertebrata is not merely remarkable for its high development, relatively to the remainder of the structure: it is also distinguished by the possession of parts to

which we have nothing analogous in the lower tribes, and by the mode in which these are concentrated and combined, so as to form one continuous mass, instead of consisting of a series of scattered ganglia.—The chief parts which are newly introduced (so to speak) in this sub-kingdom, are the Cerebral Hemispheres and Cerebellum; of which there are no traces whatever in the lower Articulata and Mollusca, and but very doubtful representations in the highest. These are superimposed, as it were, upon the cephalic ganglia connected with the organs of special sense, and upon the cords that connect them with the first ganglion of the trunk.—Again, we find that the locomotive ganglia, which formed the long knotted cord of the Articulata, are united with the centres of the respiratory system, and with those of the stomato-gastric system, to form one continuous tract, which commences anteriorly from the ganglia of special sense, and runs backwards* without interruption, in the canal of the Vertebral column, forming the Spinal Cord. This is a *continuous* instead of an *interrupted* ganglionic mass; it is composed of two lateral halves, precisely similar to each other; and each of these consists of two parts, as distinct from each other as the two tracts in the ventral cord of the Articulata,—namely, a *fibrous* structure, which connects every part of it with the Encephalon (or collection of nervous masses within the cranium), and which also serves to connect together the different parts of the cord itself,—and a *vesicular* portion, which forms the proper centre of a portion of the fibres entering into the roots of those nerves. The upper portion of the Spinal cord, which is prolonged into the cranium, and comes into immediate relation with the Encephalon, is termed the *Medulla Oblongata*. It is in this that the centres of the respiratory and stomato-gastric nerves are found; the situation of these important ganglia within the cranium, being obviously destined to protect them from those injuries to which the Spinal Cord itself is liable.

868. Thus, then, we are led to recognize in the Nervous system of Vertebrata the following fundamental parts.—1. A system of ganglia subservient to the reflex actions of the organs of *locomotion*, and corresponding with the chain of pedal or locomotive ganglia that makes-up the chief part of the ventral cord of the Articulata; in this system, the grey or vesicular matter forms one continuous tract, which occupies the interior of the *Spinal Cord*.—2. A ganglionic centre for the movements of *respiration*, and another for those of *mastication* and *deglutition;* these, with part of the preceding, make-up the proper substance of the *Medulla Oblongata*. —3. A series of ganglia in immediate connection with the organs of *Special Sense;* these are situated within the cranium, at the

* When we speak of the Vertebrata generally, their bodies are of course supposed to be in a horizontal position,—not vertical, as in Man.

anterior extremity of the Medulla Oblongata; and, in the lowest Vertebrata, they constitute by far the largest portion of the entire Encephalon.—4. The *Cerebellum*, which is a sort of off-shoot from the upper extremity of the Medulla Oblongata, lying behind the preceding.—5. The *Cerebral Hemispheres*, a pair of ganglionic masses, which lie upon the ganglia of special sense, capping them over more or less completely, according to their relative development.—These last two organs exist in the lowest Vertebrata, as in Invertebrated animals generally, in quite a rudimentary state; but their development, relatively to other parts of the Encephalon, and to the entire bulk of the animal, increases as we ascend the scale; so that in Man and the higher Mammalia they constitute by far the larger portion of the Nervous centres, and are essential to the greater part of the operations of the Nervous system. The development of the *Cerebral Hemispheres* bears a close relation to the increase of the *Intelligence*, and to the predominance of the *Will* over the involuntary impulses. The increased size of the Cerebellum, on the other hand, seems connected with the necessity which exists for the adjustment and combination of the locomotive powers, when the variety in the movements performed by the animal is great, and a more perfect harmony is required among them.—A sketch of the mode in which these different parts are combined and arranged in the several classes of Vertebrata, and of their relative development in each, will aid us in the subsequent more detailed examination of their functions.

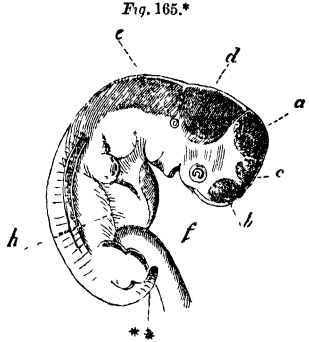
869. In the class of *Fishes*, taken as a whole, the Encephalon bears a much smaller proportion to the Spinal Cord, than it does in the higher Vertebrata. In the curious *Amphioxus* or Lancelet, there is no discoverable nervous mass above the Medulla Oblongata; so that this animal is regularly formed upon the plan which occasionally presents itself as a monstrosity in Man,—namely, having the Spinal Cord and Medulla Oblongata for the whole of the nervous centres, and being *anencephalous* or destitute of any proper encephalon. In some of the lowest Vermiform (worm-like) Fishes, such as the Lamprey, the cephalic masses are very little more developed in proportion to the Spinal Cord, than are the cephalic ganglia of Insects in reference to their chain of ventral ganglia. But as the organs of special sense acquire a more complete evolution, we find the ganglia connected with them presenting a greatly increased size. On opening the cranial cavity of a Fish, we usually observe four nervous masses (three of them in pairs) lying, one in front of the other, nearly in the same line with the Spinal cord. The first or most anterior of these are the *Olfactory ganglia* (Plate II., Figs. 5, 6, 7, *a*), or the ganglia of the nerves of smell; the nature of which is known, from their being situated at the origin of the Olfactory nerves. In the Shark and some other Fishes, these are separated from the rest by peduncles or footstalks; a

fact of much interest, as explaining the arrangement which we find in Man. What is commonly termed the *trunk* of *his* Olfactive nerve is really the commissure connecting the Olfactive ganglion (known as the bulbous enlargement that lies upon the cribriform plate of the ethmoid bone) with the other portions of his Encephalon; the proper fibres of the nerve being those which come-off from this ganglion, in the numerous branches that proceed from it into the nasal cavity.—Behind the Olfactive ganglia is a pair of masses (*b*, *b*), of which the relative size varies greatly in different Fishes. Thus in the Perch, whose Encephalon is here figured, their size is intermediate between that of the first and third pairs; being as much inferior to that of the third, as it is superior to that of the first. On the other hand, in the Shark and several other Fishes, they are considerably larger than the succeeding pair. These second ganglia are commonly considered as the rudiments of the *Cerebral Hemispheres;* but there seems reason for regarding them as chiefly the representatives of the *corpora striata;* the existence of a Cerebrum being only indicated by a thin layer of vesicular matter, which overlies the ventricle that is found in these bodies in the brains of Cartilaginous Fishes alone.—Behind them, and forming the third pair of ganglionic masses (*c*, *c*), are two large bodies, from which the optic nerves arise; these evidently represent the *Optic ganglia*, which constitute the principal mass of the cephalic ganglia in Insects and the higher Mollusca, and with which the Corpora Quadrigemina of higher Vertebrata partly correspond; but they probably represent also the *Thalami Optici* of the brain of Man and the higher animals.—At the back of these, overlying the top of the spinal cord, is a single mass (*d*), the *Cerebellum*. This, also, varies greatly in its relative dimensions, being much more highly developed in the active and rapacious Sharks, than it is in Fishes of inferior muscular energy and variety of movement.—The Spinal Cord (*e*) is divided at the top by a fissure, which is most wide and deep beneath the Cerebellum, where there is a complete separation between its two halves. This opening corresponds to that through which the œsophagus passes in the Invertebrata; but as the entire nervous mass of Vertebrated animals lies above the alimentary canal (or nearer the dorsal surface), it does not serve the same purpose in them; and in the higher classes, the fissure is almost entirely closed by the union of the two halves on the median plane, the *fourth* ventricle, however, being a remnant of it. This cavity is partly seen in Fig. 7, which is a vertical section of the brain whose upper and under surfaces are shown in Figs. 5 and 6. —In the lateral strands of the Medulla Oblongata, close to the fourth ventricle, there is a pair of ganglionic centres (characterized by the presence of vesicular matter), in which the Auditory nerve terminates; and these are sometimes developed as distinct ganglionic enlargements. Other separate ganglia, sometimes of considerable

size, are very commonly found at the origin of the Par Vagum.—It is curious to notice the very large comparative size of the Pineal gland (*f*), and of the Pituitary body (*h*), in this class; the functions of these organs are entirely unknown.

870. The analogy of the Optic lobes of Fishes to the Corpora Quadrigemina and Thalami Optici of the fully-formed brain of the higher Vertebrata, is not so complete as it is to certain parts which occupy their place at an earlier period. In the Human Embryo, at about the 6th week, the Encephalon consists of a series of vesicles arranged in a line with each other; of which those that represent the Cerebrum (*b*, Fig. 165) are the smallest, whilst that which

Fig. 165.*



represents the Cerebellum (*d*) is the largest. Between the cerebral and the cerebellic vesicles, are *two* others (*c* and *a*), of which the posterior one is for the Optic ganglion, and answers to the Tubercula Quadrigemina; whilst the anterior contains the Third Ventricle, and corresponds in some degree to the Thalami Optici. This condition is precisely represented in the Lamprey; but the optic ganglia, and the parts surrounding the third ventricle, form but one lobe in most Fishes; so that the third ventricle seems hollowed-out of the optic ganglia, as shown in Plate II., Fig. 7, *c*.

871. The Encephalon of *Reptiles* does not show any considerable advance in its general structure, above that of the higher Fishes. The Cerebral Hemispheres (Plate II., Figs. 8, 9, 10, *b*) are always much larger than the Olfactive and Optic ganglia; and they gene-

* Human Embryo of sixth week, enlarged about three times —*a*, vesicle of corpora quadrigemina; *b*, vesicle of cerebral hemispheres; *c*, vesicle of thalami optici and third ventricle; *d*, vesicle for cerebellum and medulla oblongata, *e*, auditory vesicle; *f*, olfactory fossa; *h*, liver; ** caudal extremity.

rally cover-in the latter (*c*, *c*) in part, by their posterior extremities. The Cerebellum is almost invariably of small proportionate dimensions; and this is especially the case in the Frog, in which it does not even cover-in the fourth ventricle. This low development of the Cerebellum in Reptiles, is what might be anticipated from the general inertness of these animals, and the want of variety in their movements. The Spinal Cord is still very large, in proportion to the nervous masses contained in the skull; and, as we shall hereafter see, its power of keeping-up the movements of the body, after it has been cut-off from all connection with the brain, is very considerable.—We find that, in Reptiles, as in Fishes, the Spinal Cord may have a nearly uniform size from one extremity to the other, like the ventral cord of the lower Articulata; or it may present considerable enlargements at particular spots, like the ganglionic cord in the thoracic region of Insects. This difference depends upon the degree of development of the special locomotive organs. Thus in the Eel and Serpent, whose movements are accomplished by the undulations of the entire trunk, and which are destitute of members, we find a uniform development of ganglionic matter in the spinal cord. On the other hand, in the Flying-fish, in which the pectoral fins or anterior extremities effect the greater part of the propulsion of the body, we find a great ganglionic enlargement of the Spinal cord at the part with which the nerves of those members are connected: in the Frog, whose movements are chiefly effected by the posterior extremities, we find a similar enlargement at the roots of the crural nerves: and in the Turtles and Lizards, the two pairs of whose members are nearly similar in function, and serve to effect the principal movements of the body, we find an anterior and a posterior enlargement of the Spinal Cord corresponding to the parts with which the nerves of these members are connected.

872. We find in *Birds* a considerable advance in the character of the Encephalon, towards that which it presents in Mammalia. The Cerebral Hemispheres (Plate II., Figs. 11, 12, 13, *b*) are greatly increased in size; and they cover-in, not merely the olfactory ganglia, but in great part also the optic ganglia. The former are of comparatively small size, the organ of smell in Birds not being much developed: the latter are very large, in conformity with the acuteness of sight which is highly characteristic of the class. The Cerebellum is of large size, as we should expect from the number and complexity of the muscular movements performed by animals of this class; but it consists chiefly of the central lobe, with little appearance of lateral hemispheres. The Spinal Cord is still of considerable size in comparison with the Encephalon; and it is much enlarged at the points whence the legs and wings originate. In the species which have the most energetic flight, such as the Swallow, the enlargement is the greatest where the nerves

of the wings come-off; but in those which, like the Ostrich, move principally by running on the ground, the posterior enlargement, from which the legs are supplied with nerves, is much the more considerable.

873. In the *Mammalia*, we find the size and general development of the Encephalon presenting a gradual increase, as we ascend the series from the non-placental Monotremes and Marsupials towards Man. In the former, the Hemispheres exhibit no convolutions; and the great transverse commissure, or connecting band of fibrous structure, termed the *corpus callosum*, is deficient. As we rise through the true viviparous division of the class, we notice a gradually-increasing prolongation of the Cerebral hemispheres backwards; so that first the Optic ganglia, and then the Cerebellum, are covered-in by them. The latter partly shows itself, however, in all but Man and the Quadrumana, when we look at the brain from above downwards; as we see in the Encephalon of the Sheep (Plate II., Figs. 14, 15, *d*). The Cerebral hemispheres increase, not only in size, but also in complexity of structure, both external and internal. Their exterior, instead of remaining smooth, is marked by convolutions, which serve to extend very greatly the amount of surface over which blood-vessels can pass into the grey substance. Their internal structure becomes more complex, in the same proportion as their size and the depth of their convolutions increase; and in Man all these conditions present themselves in a far higher degree than in any other animal. The number of commissural bands, connecting the two hemispheres with each other transversely, and uniting their anterior and posterior portions, is very greatly increased; and in fact, a large proportion of their mass is composed, in Man and the higher Mammalia, of fibres of this character.—In proportion to the increase of the Cerebral hemispheres, there is a relative diminution in the size of the ganglia of special sense; but their dimensions, as compared with the entire bulk of the animal, are by no means reduced, but are even increased. The Olfactive ganglia (Fig. 14, *a*) are always readily discoverable, being separated from the remainder of the encephalic masses by a peduncle on each side. The Optic ganglia (Fig. 15, *c*), on the other hand, are so completely covered-in by the Hemispheres, that it is only when the latter are turned-aside that we can discern them. They differ in external aspect from the optic ganglia of Birds and the lower Vertebrata; being divided by a transverse furrow into anterior and posterior eminences, whence they are known as the Corpora Quadrigemina. The Auditory ganglia are lodged in the substance of the Medulla Oblongata, forming the 'grey nuclei' of the strands termed the 'posterior pyramids;' and similar nuclei in the 'restiform bodies' are the ganglionic centres of the Glosso-pharyngeal nerves, and perhaps minister to the sense of Taste. Besides these, however, are the two large bodies termed

the *corpora striata* and *thalami optici*, which have been commonly considered as appendages of the Cerebrum, but which must undoubtedly be regarded as independent of it, and as constituting independent ganglionic centres, whose development bears no constant proportion to that of the Cerebrum. From the peculiar relation presently to be described (§ 901), which these bodies bear, on the one hand to the Spinal Cord, and on the other to the rest of the Encephalon, there seems strong reason to believe that they together constitute the ganglionic centre of the sense of Touch, and of the motions which are automatically prompted by it.—The Cerebellum is chiefly remarkable for the development of its lateral parts or hemispheres, and for the intricate arrangement of the grey and white matter in them (Fig. 15, *d*); the central portion, sometimes called the vermiform process, is relatively less developed than in those lower Vertebrata in which it forms the entire organ. —The Spinal Cord is much reduced in size, when compared with other parts of the nervous centres; the motions of the animals of this class being more dependent upon their will, or guided by their sensations; and the simply-reflex actions bearing a much smaller proportion to the rest. The development of ganglionic enlargements, in accordance with the presence or absence of high locomotive powers in the extremities, follows the same rule as in the preceding classes.

3. *Functions of the Spinal Cord and its Nerves.*

874. In commencing our more detailed examination into the functions of the different parts of the Nervous system in Vertebrated animals, it seems best to commence with the Spinal Cord; this being the portion whose presence is most essential to the continuance of life. As already mentioned, Infants are sometimes born without any Cerebrum or Cerebellum; and such have existed for several hours or even days, breathing, crying, sucking, and performing various other movements. The Cerebrum and Cerebellum have been experimentally removed from Birds and young Mammalia, thus reducing these beings to a similar condition; and all their vital operations have, nevertheless, been so regularly performed, as to enable them to live for weeks or even months. In the Amphioxus, as already remarked, we have an example of a completely-formed adult animal, in which no rudiment of a Cerebrum or Cerebellum can be detected. And in ordinary profound sleep, or in apoplexy, the functions of these organs are so completely suspended, that the animal is for a time, in all essential particulars, in the same condition as if destitute of them. It is possible, indeed, to reduce a Vertebrated animal to the condition (so far as its nervous system is concerned) of an Ascidian Mollusk (§ 850); for it may continue to exist for some time, when not

merely the Cerebrum and Cerebellum have been removed from above, but when nearly the whole Spinal Cord has been removed from below,—that part only of the latter being left, which, being the centre of the respiratory actions, corresponds to the single ganglion of the Tunicata. On the other hand, no animal can exist by its Encephalon alone, the Spinal Cord being destroyed or removed; for the reflex actions of the latter are so essential to the continuance of its respiration, and consequently of its circulation, that if they be suspended (by the destruction of the portion of the cord which is concerned in them), all the organic functions must soon cease.

875. Although the Spinal Cord was formerly regarded as little else than a bundle of nerves proceeding from the Brain, yet its true rank as a distinct centre of nervous power is now universally admitted. That the actions prompted by it, when these do not originate in one of the higher centres, are of a purely *reflex* nature, consisting in the excitement of muscular movements in respondence to external impressions, without the necessary intervention of sensation,—appears to be a necessary inference from the facts that have been brought to light by experiment and observation. Experiments on the nature of this function are best made upon cold-blooded animals; as their general functions are less disturbed by the effects of severe injuries of the nervous system, than are those of Birds and Mammals. When the Cerebrum has been removed, or its functions have been suspended by a severe blow upon the head, a variety of motions may be excited by their appropriate stimuli. Thus, if the edge of the eyelids be touched with a straw, the lid immediately closes. If a candle be brought near the eye, the pupil contracts. If liquid be poured into the mouth, or a solid substance be pushed within the grasp of the muscles of deglutition, it is swallowed. If the foot be pinched, or burned with a lighted taper, it is withdrawn; and (if the animal experimented on be a Frog) the animal will leap away, as if to escape from the source of irritation. If the cloaca be irritated with a probe, the hind-legs will endeavour to push it away.

876. Now the performance of these as well as of other movements, many of them most remarkably adapted to an evident purpose, might be supposed to indicate that *sensations* are called-up by the impressions; and that the animal can not only *feel*, but can *voluntarily* direct its movements, so as to get rid of the irritation which annoys it. But such an inference would be inconsistent with other facts.—In the first place, the motions performed by an animal under such circumstances are never spontaneous, but are always excited by a *stimulus* of some kind. Thus, a decapitated Frog, after the first violent convulsive movements occasioned by the operation have passed away, remains at rest until it is touched; and then the leg, or its whole body, may be thrown into sudden

action, which immediately subsides again. In the same manner, the act of swallowing is not performed, except when it is excited by the contact of food or liquid; and even the respiratory movements, spontaneous as they seem to be, would not continue, unless they were continually re-excited by the presence of venous blood in the vessels or of carbonic acid in the air-cells of the lungs. These movements are all *necessarily* linked with the stimulus that excites them; that is, the same stimulus will always produce the same movement, when the condition of the body is the same. Hence it is evident that the judgment and will are not concerned in producing them; and that the *adaptiveness* of the movements is no proof of the existence of consciousness and discrimination in the being that executes them,—the adaptation being made *for* the being, by the peculiar structure of its nervous apparatus, which causes a certain movement to be executed in respondence to a given impression,—not *by* it. An animal thus circumstanced may be not unaptly compared to an automaton, in which particular movements, adapted to produce a given effect, are produced by touching certain springs. The source of the adaptation is here in the mind of the maker or designer of the automaton; and so it evidently is in the case of the reflex or consensual movements of animals, as well as of those various operations of their nutritive system over which they have no control, yet which concur most admirably to a common end.

877. Again, we find that such movements may be performed, not only when the Brain has been removed, the Spinal cord remaining entire, but also when the Spinal cord has been itself cut across, so as to be divided into two or more portions, each of them completely isolated from each other and from other parts of the nervous centres. Thus, if the head of a Frog be cut-off, and its spinal cord be divided in the middle of the back, so that its fore-legs remain connected with the upper part, and its hind-legs with the lower, each pair of members may be excited to movement by a stimulus applied to itself; but the two pairs will not exhibit any consentaneous motions, as they will do when the spinal cord is undivided. Or, if the Spinal cord be cut across, without the removal of the Brain, the lower limbs may be *excited* to movement, by an appropriate stimulus, though they are completely paralyzed to the *will;* whilst the upper remains under the control of the animal, as completely as before. Now it is not conceivable that, in this last case, sensation and volition should exist in that portion of the spinal cord which remains connected with the nerves of the posterior extremities, but which is cut-off from the brain. For, if it were so, there must be two distinct centres in the same animal, the attributes of the brain not being effected; and, by dividing the spinal cord into two or more segments, we might thus create in the body of one animal two or more distinct centres of sensation, inde-

pendent of that which still holds its proper place in the Encephalon. To say that two or more distinct centres of sensation are present in such a case, would really be in effect the same as saying, that there are two or more distinct *minds* in one body,—which is manifestly absurd.

878. But the best proofs of the limitation of the endowments of the Spinal Cord, are derived from the phenomena presented by the Human subject, in cases where that organ has suffered injury by disease or accident in the middle of the back. We find that when this injury has been severe enough to produce the effect of a complete division of the Cord, there is not only a total want of voluntary control over the lower extremities, but a complete absence of sensation also,—the individual not being in the least conscious of any impression made upon them. When the lower segment of the Cord remains sound, and its nervous connections with the limbs are unimpaired, distinct reflex movements may be excited in the limbs, by stimuli directly applied to them, as, for instance, by pinching the skin, tickling the sole of the foot, or applying a hot plate to its surface; and this without the least sensation on the part of the patient, either of the cause of the movement, or of the movement itself. This fact, taken in connection with the preceding experiments both upon Vertebrated and Articulated animals, distinctly proves that sensation is *not* a necessary link in the chain of reflex actions: but that all which is required is an *afferent* fibre, capable of receiving the impression made upon the surface, and of conveying it to the centre; a *ganglionic centre*, composed of vesicular nervous substance, into which the afferent fibre passes; and an *efferent* fibre, capable of transmitting the motor impulse from the ganglionic centre to the muscle which is to be thrown into contraction.

879. These conditions are realized in the Spinal Cord. We may have reflex actions excited through any one isolated segment of it, as through a single ganglion of the ventral cord of Articulata; but they are then confined to the parts supplied by the nerves of that segment. Thus if the spinal cord of a Frog be divided just above the origin of the crural nerves, the hind-legs may be thrown into reflex contraction by various stimuli applied to themselves, whilst the fore-legs will exhibit no movement of this kind. But when the brain has been removed, and the Spinal Cord is left entire, movements may be excited in distant parts, as, for example, in the fore-legs, by any powerful irritation of the posterior extremities, and *vice versâ*. This is particularly well seen in the convulsive movements which take place in certain disordered states of the nervous system; a slight local irritation being sufficient to throw almost any muscle of the body into a state of energetic action (§ 885). And a similar state may be artificially induced, by applying Strychnine (in solution) to the Spinal Cord of a decapitated Frog.

880. The minute anatomy of the Spinal Cord is a subject of great difficulty; and our notions of the course of the fibres within it are rather founded upon physiological phenomena, and upon the more evident structure of the ventral column in Articulata, than upon what can be clearly demonstrated in Vertebrated animals.—The *roots* of the Spinal nerves are all distinctly separable into an anterior and a posterior fasciculus; and it is certain that these fasciculi have entirely opposite functions. If they be laid bare, and the anterior fasciculus of any spinal nerve be touched, violent contractions are immediately seen in the muscles supplied by that nerve; these contractions are as strongly manifested, if the anterior roots be divided and their separated ends be irritated; whilst no such result follows, whatever amount of irritation be applied to the ends still in connection with the cord. Notwithstanding these violent movements, the animal shows little or no sign of pain.—On the other hand, if the posterior roots be irritated, the animal gives signs of acute pain, and no vigorous muscular contractions are produced. The movements which are witnessed are evidently of a *reflex* nature, being called-forth through the anterior roots; as is proved by their cessation when these are divided. Further, if the posterior roots be divided, and the separated ends be irritated, no effect whatever is produced, no movement being excited, and no sensation being occasioned; but if the ends still in connection with the cord be irritated, the animal shows signs of pain as before.—Hence it is evident, that the *posterior* roots are made-up of *afferent* fibres, that is, of fibres which convey impressions *towards* the nervous centres; which impressions, if confined to the cord itself, excite reflex actions; whilst, if conveyed to the brain, they call-forth sensations.—On the other hand, it is equally evident that the anterior roots are composed of *efferent* or *motor* fibres, which may serve to convey to the muscles the motor impulses originating in the nervous centres; these impulses may be occasioned by the reflex action of the Spinal cord; or they may descend from the Brain, where they have been generated by a consensual, emotional, or ideational impulse, or by an act of the Will.

881. The Spinal Cord is a completely *double* tract; being composed of two distinct halves, united together on the median plane by numerous commissural fibres. This union is much closer in Man and the Mammalia, than it is in the lower Vertebrata; but the division is still marked externally, by a deep fissure on the anterior surface of the cord, and by a shallower one on its posterior aspect. Its surface is traversed, moreover, by two furrows on each side; so that each half is divided into three columns, the *anterior*, *lateral*, and *posterior*. The anterior roots of the spinal nerves join the Cord for the most part along the line of the anterior furrow; and the posterior along the line of the posterior furrow: so that the middle or lateral column lies between them, the anterior

column being altogether in front of them, and the posterior column behind them. When a transverse section of the Cord is made, it is seen to contain, on each side, a crescentic patch of grey or vesicular substance; the points of each crescent are directed towards the anterior and posterior furrows of its own side respectively; whilst the convexities of the two crescents approach one another near the median plane, and are connected by a transverse tract, which consists partly of vesicular and partly of fibrous substance. The remainder of the cord is made-up of white or tubular substance, the course of whose fibres is for the most part longitudinal.—The posterior peak of the crescentic patch of grey matter approaches very closely to the bottom of the posterior furrow; whilst the anterior peak does not come into nearly the same degree of proximity with the bottom of the anterior furrow. Hence it is considered by some, that the lateral or middle columns of the cord, being much less completely isolated from the anterior columns than they are from the posterior, should be associated with the former, under the name of *antero-lateral* columns.

882. Upon tracing the roots of the nerves into the substance of the Cord, the connection of a part of their fibres with its grey or vesicular matter is easily made evident. Of these fibres, therefore, it serves as the proper ganglionic centre. There is reason to believe, both from anatomical investigation, and from physiological phenomena, that, as in the Articulata (§ 857), a part of the afferent or excitor fibres, after traversing the grey substance, pass-out on the *same* side as the efferent or motor; whilst another portion crosses to the *opposite* side, and forms part of *its* efferent trunks.—It is pretty certain that other fibres of the roots become continuous with the longitudinal fibres that form the white strands of the Spinal Cord; but the chief part of the longitudinal strands of the Cord is apparently made-up of commissural fibres which establish an intimate connection between its different segments, as in Insects; and there seems good ground for considering even those which pass up by the Medulla Oblongata, so as to connect themselves with the Encephalic centres, as of the same commissural character, and as not correctly appertaining to the Cerebrum (§ 914).—The thickness of the Spinal Cord differs considerably at its different parts. Thus in the cervical region, there is an enlargement corresponding with the origins of the nerves that form the brachial plexus; this enlargement is partly caused by an increase in the amount of grey matter; but the amount of fibrous structure, also, is much greater than at the upper part of the cervical region. On the other hand, there is a still greater enlargement of the cord in the lumbar region, at the part whence the nerves of the lower extremities arise; and this enlargement is caused by the great increase in the amount both of the grey matter and of the white at that point. It may be easily shown by direct measurement, that the fibrous strands of the upper

cervical region would not by any means serve to carry onwards to the brain those of the lumbar region alone, much less with the addition of other fibres proceeding from all the intermediate nerves. Further, if the fibrous strands were for the most part (as formerly supposed) directly continuous between the brain and the roots of the spinal nerves, the white portion of the Spinal Cord, in such animals as Serpents, in which it has no ganglionic enlargements, should progressively diminish in diameter with every pair of nerves into which it sends fibres, from its cephalic to its caudal extremity; this, however, is by no means the case, the Spinal cord of Serpents being remarkable for its uniform diameter throughout.—It is obvious, then, that by far the larger proportion of the white fibres of the Spinal Cord must belong to itself alone, establishing an intimate mutual connection between its different segments and the nerves proceeding from them. And we shall see that all the phenomena which have been supposed to indicate an immediate communication between the Brain and the nerves, admit of another and more satisfactory explanation.

883. It was supposed by Sir C. Bell (who was the first to determine the relative functions of the two roots of the spinal nerves in Vertebrated animals), that the anterior columns of the Spinal cord have a function corresponding to that of the anterior roots of the spinal nerves; and the posterior columns with the posterior roots. But from the difficulty of tracing the connection between the longitudinal fibres of the cord, and any portion of the roots, it is at present impossible to say how far there is any anatomical reason for the assumption of this correspondence; and it is quite certain that the physiological facts at present known, both from experiment and from observation of the effects of disease or injury upon different tracts of the spinal cord, do not bear-out the supposition. As to what the precise functions of the several columns are, however, it is not easy to form any other conjecture that shall be consistent with all the phenomena.

884. Of the particular Reflex actions to which the Spinal Cord (using that term in its limited sense, as excluding the Medulla Oblongata) is subservient, those most connected with the organic functions have already been noticed. They are chiefly of an *expulsive* kind; being destined to force-out the contents of various cavities of the body. Thus the ordinary acts of defecation and urination, the ejaculatio seminis and parturition, are all reflex actions, over which the will has a greater or less degree of control; being able to keep the two former ones in check, so long as the stimulus is not very violent, and being also capable of effecting them by itself; but having no control over the two latter, either by way of acceleration or prevention, when once the stimulus by which they are excited has come into full action.—The movements of the posterior extremities are among the most remarkable of those

which seem due to the action of the proper Spinal Cord. It has been already noticed (§ 878) that these may be excited, even in Man, when the spinal cord has been severed in the middle without injury to its lower segment; and it is remarkable that gentle stimuli applied to the skin of the sole of the foot, appear the most capable of producing them. We have seen how completely, in the lower animals, the acts of progression may be sustained, by the repeated stimulus of the contact of the ground, or of fluid, without any influence from the cephalic ganglia (§§ 858, 859); the power of these being limited, it would seem, to the control and direction of them. And there is strong reason to believe that so far as the ordinary acts of locomotion are concerned, the movements of the inferior extremities in Man may be performed on the same plan, being sustained by the reflex influence of the successive impulses of the feet upon the ground, when once set in action by the will, whilst we are walking steadily onwards,—the mind being at the same time occupied by some train of thought, which engrosses its whole attention. There are few persons to whom it has not occasionally happened, that, on awaking (as it were) from their reverie, they have found themselves in a place very different from that to which they had intended going; and even when the consciousness is sufficiently on the alert to allow sensations to guide, direct, and control the motions of the limbs, their actions appear to be performed without the agency of the will, which may be entirely concentrated upon some interior mental operation. It is certain that, in Birds, the movements of flight may be performed after the removal of the Cerebrum.

885. There are many irregular or abnormal reflex actions, performed through the instrumentality of the Spinal Cord, the study of which is of the highest importance to the Medical Man. It is probable that *all* Convulsive movements are produced through its agency, with that of the Medulla Oblongata and Sensory ganglia; for it has been found, by repeated experiments, that these movements are never produced by injuries of the Cerebral hemispheres.—Convulsive movements may be of three kinds. 1. They may be simply *reflex;* being the natural result of some extraordinary irritation. 2. They may be simply *centric;* depending upon a peculiar condition of the ganglionic centre of the Spinal Cord, which occasions muscular movements without any stimulation. This may be dependent upon an abnormal state of the Blood. We know that it may be produced by the introduction of certain poisons (as strychnia) into the circulation; and it is probable that morbid matters generated within the body may have the same effect. 3. They may depend upon the combined action of both principles; the nervous centres being in a highly irritable state, which causes very slight irritations (such as would otherwise be inoperative) to excite violent reflex or convulsive movements. This last is by far the most common cause

of the convulsive actions that occur in various diseased conditions of the system. Thus, convulsions are not unfrequent in children during the period of teething; being produced by the irritation which results from the pressure of the tooth, as it rises against the unyielding gum. In this case, the stimulus would scarcely be sufficient to produce the violent result, were it not for a peculiarly excitable state of the Spinal Cord, brought-about by various causes. In like manner, when such an excitable state exists, convulsions may be occasioned by the presence of intestinal worms, of irritating substances, or even simply of undigested matters, in the alimentary canal; and will cease as soon as they are cleared-out, in the same manner as the convulsions of teething may often be at once checked by the free lancing of the gums.

886. The influence of the condition of the Spinal Cord itself, is peculiarly seen in the convulsive diseases termed Hydrophobia, Tetanus, Epilepsy, and Hysteria.—In the first of these, not only the Spinal Cord, but the Medulla Oblongata, and the ganglia of Special Sense, are involved; their peculiar condition being the result, it would appear, of the introduction of a poison into the blood. It is most remarkable that the Cerebrum should so completely escape its influence. When the state of intense excitability in these centres is once established, the slightest stimulus is sufficient to bring-about convulsive movements of the utmost violence. It is characteristic of this complaint, that the stimuli most effectual in exciting the movements, are those which act through the nerves of special sense; thus the *sight* or the *sound* of water will bring-on the paroxysm, and any attempt to *taste* it increases the severity of the convulsions.—In Tetanus there appears to be a similarly excitable state of the Spinal Cord and Medulla Oblongata, not involving the ganglia of special sense. This may be the result of causes altogether internal, as in the idiopathic form of the disease; in which the condition exactly resembles that which may be artificially induced by the administration of Strychnine, or by its application to the cord. Or it may be first occasioned by some local irritation, as that of a lacerated wound; the irritation of the injured nerve being propagated to the nervous centres, and establishing the excitable state in them. When the complaint has once established itself, the removal of the original cause of irritation (as by the amputation of the injured limb) is seldom of any avail; since the slightest impressions upon almost any part of the body, are sufficient to excite the tetanic spasm.—In like manner, Epilepsy, which consists in convulsive actions with temporary suspension of the functions of the Encephalon, may result from the irritation of local causes, like the convulsions of teething; and may cease, like them, when the sources of irritation are removed. But when it becomes confirmed, it seems to involve a disorder of the nervous centres which no local treatment can influence.

887. These and other forms of Convulsive disorder, when productive of a fatal result, usually act by suspending the respiratory movements; the muscles which effect these being fixed by the spasms, so that the air cannot pass either in or out, and suffocation takes-place as completely as if the entrance to the air-passages were closed. It is remarkable that every one of them may be imitated by *Hysteria;* a state of the nervous system that is characterized by its peculiar excitability, but in which there is no such fixed tendency to irregular action as would indicate any positive disease,—one form of convulsion often taking the place of another, at short intervals, with the most wonderful variety. It will often be found that the convulsions may be immediately traced to some local irritation; thus they are particularly liable to occur at the catamenial periods, especially if the menstrual flux be deficient; but it does not seem improbable, that here too the presence of some morbid matter in the blood has much to do with the development of that peculiar excitability, which gives to slight local irritations such a powerful agency.

888. *Peculiarities of Spinal Nerves.*—The statement that the nerves of the Spinal Cord arise by double roots, is not without exception as to some which arise from its cranial prolongation, and which are distributed to the parts of the head and neck. The *first spinal* nerve or *Sub-occipital* (the 10th pair of Willis) not unfrequently arises by a single set of roots from the anterior portion of the cord; and it is then purely motor, except in virtue of its inosculation with other nerves. The *Hypoglossal* (9th pair of Willis) appears to be also a purely motor nerve; arising by one set of roots, and being distributed entirely to the *muscles* of the tongue, which organ derives its sensibility from other nerves. The *Glosso-Pharyngeal* usually arises from a single set of roots, and these correspond with the posterior roots of the spinal nerves; in some animals, however, and occasionally in Man, there is a distinct anterior root, and the nerve acquires direct motor functions. It may in some respects be considered as making-up, with the preceding, an ordinary spinal nerve. The *Spinal Accessory,* again, appears to be chiefly or entirely a motor nerve at its origin; and in like manner the *Pneumogastric,* or Par Vagum, seems at its roots to correspond with the posterior roots of the ordinary spinal nerves, and to execute functions analogous to theirs; but these two nerves exchange fibres, so that each acquires in part the endowments of the other. The *Facial* nerve (or portio dura of the 7th), which is the nerve that supplies the muscles of the head in general, arises by a single root, and is exclusively motor in its properties, except in branches which have received sensory filaments by inosculation with other nerves. The same is the case also, with the *Motor Nerves of the Orbit* (the 3rd, 4th, and 6th, of Willis), which arise by single roots, and which have no sensory endowments but those which they obtain by inosculation

with the Fifth pair.—On the other hand, the *Fifth* pair arises by a double root; that which corresponds to the anterior or motor root of the spinal nerves is very small, however, and only enters the third division of the nerve, which supplies the muscles concerned in mastication; the other root, corresponding with the posterior roots of the spinal nerves, is of large size, and its branches are distributed to the face and head, endowing them with sensibility. Thus the *sensory* division of the Fifth pair, being distributed, not merely to the same parts with its motor division, but also to the parts which derive their motor endowments from the Facial nerve and from the nerves of the Orbit, may be regarded as making-up, together with all of them, one ordinary Spinal nerve.

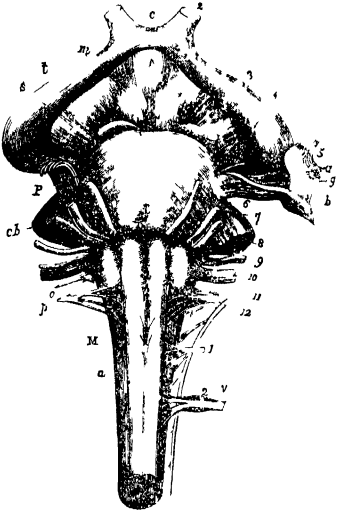
4. *Functions of the Medulla Oblongata.*

889. This portion of the nervous centres, as already stated, does not differ in any essential particular from the Spinal Cord, of which it may be considered as a cranial prolongation. But the arrangement of its constituent parts is peculiar; for whilst it is the medium by which the various strands of the Spinal Cord are connected with the different portions of the Encephalon, it is also remarkable as being the ganglionic centre concerned in the maintenance of the action of respiration and in the ingestion of food. Four principal strands of nervous matter may be distinguished anatomically, in each of its lateral halves; these are, anteriorly, the *Anterior Pyramids;* next, the *Olivary* bodies; next, the *Restiform* bodies; and lastly, the *Posterior Pyramids.* It will be presently seen, however, that the physiological relations of these strands, as indicated by their connections with the Encephalon above, with the Spinal Cord below, and with the nerves that have their centres in them, are very different from what their mere relative positions would indicate.—The grey or vesicular substance in this part, no longer holds the relation to the white that it possesses in the Spinal Cord; but is principally aggregated in three pairs of ganglionic centre, of which the *anterior* forms the nucleus of the Olivary body, the *lateral* of the Restiform, and the *posterior* of the Posterior Pyramidal.

890. The *Anterior Pyramids* (Fig. 166, *p*) consist entirely of fibrous structure, and establish a communication between the motor tract at the base of the Encephalon (which is chiefly derived from the Corpora Striata) and the anterior and antero-lateral columns of the Spinal Cord. They have also a connection with the Cerebellum. A large part of their fibres decussate (*d*), those that proceed from the right hemisphere passing into the left side of the cord, and those from the left hemisphere into the right side of the cord; an arrangement which explains the fact, that in Hemiplegia, the paralytic affection of the body is on the side opposite to

that of the lesion of the brain. A small proportion of the fibres of the anterior pyramids does not decussate, and this passes down, with fibres from the Olivary columns, into the anterior columns of the

Fig 166 *



cord, whilst the decussating fibres dip more deeply away from the anterior surface of the cord, and connect themselves rather with its lateral or middle columns

891 The *fibrous* portion of the *Olivary* bodies (*o*) is connected above with the Motor tract, with the Corpora Quadrigemina, and with the Cerebellum, and below with the anterior columns of the Spinal Cord —The vesicular nucleus of each Olivary body, on the other hand, which is known as the *corpus dentatum*, seems to be especially connected with the origins of the nerves concerned in the

* Front view of the upper part of the Cranio Spinal Axis, with the origins of the Nerves,—M, Medulla Oblongata *p* anterior pyramids *d* their decussation, *o*, olivary bodies, P, Pons Varolii, *c b*, crura cerebelli, *s*, crura cerebri, *m*, corpora mammillaria, *t*, tractus opticus, *c*, chiasma, 2, optic nerve, 3, motor oculi, 4, patheticus, 5, fifth pair, *a*, its larger root *b* its smaller root, *g*, Gasserian ganglion, 6, abducens, 7, facial, 8, auditory 9, glosso-pharyngeal, 10, vagus, 11, spinal accessory 12, hypo glossal, 1′, first spinal nerve, 2′, second spinal nerve, *v*, its ganglion

regulation of the movements of the tongue; thus we find that anteriorly a portion of the roots of the Hypoglossal, which is the motor nerve of the tongue, issue from it; whilst posteriorly, a portion of the roots of the Glosso-pharyngeal, which is one of the sensory nerves of the tongue, seem to terminate in it.

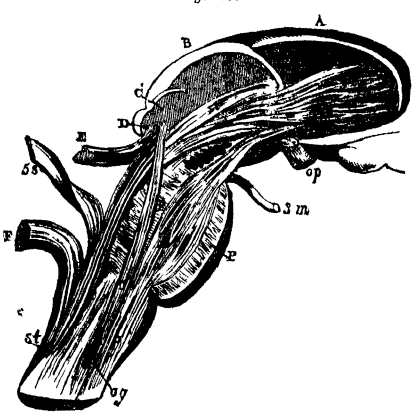
892. The fibres of the *Restiform* columns are continuous above with those of the hemispheres of the Cerebellum; and below they pass, without decussation, chiefly into the posterior columns of the Spinal Cord, a band of *arciform* fibres, however, crossing-over to the anterior and lateral columns on each side. The ganglia imbedded in these columns, however, seem to possess a completely independent function; being the centres of the Pneumogastric nerves, which are the chief excitors of the Respiratory movements, as well as of a portion of the Glosso-pharyngeal nerves.

893. The *Posterior Pyramids* are two small strands of fibrous structure, lying between the two restiform bodies, and occupying the portion of the Medulla Oblongata on either side of the posterior median furrow. They may be traced upwards into the Thalami Optici, and downwards into the posterior columns and the posterior part of the lateral. They undergo a decussation in their upward course; but it is not certain whether this decussation involves all their fibres.—The grey nuclei of the Posterior Pyramids, which are situated immediately beneath the fourth ventricle, are the ganglionic centres of the Auditory nerves, or the proper *Auditory* ganglia.

894. When we consider these various lines of communication simply in their Physiological relations, as establishing connections between the Encephalon above and the Spinal Cord below, it will be convenient first to notice and put aside the *Cerebellar*. Of these there are two sets; the principal forming the Restiform bodies, which connect the Cerebellum with the posterior columns of the Spinal cord; whilst there is another division, which comes into connection through the Olivary and Pyramidal bodies, with the anterior and antero-lateral columns.—The remaining fibres, which constitute what are improperly called the *Crura Cerebri*, may be considered as forming two principal tracts, the *sensory* and the *motor;* these being distinguished as such by the character of the nerves which arise in their course. The *sensory* tract passes upwards from the posterior columns of the Spinal Cord, and the posterior part of the lateral, to the Thalami Optici; it is obviously continuous below with the tract in which the posterior roots of the Spinal nerves terminate, and in its upward course it receives the large or sensory root of the Fifth pair; whilst passing through the Pons Varolii, it undergoes a partial decussation. On the other hand, the *motor* tract may be regarded as descending from the Corpora Striata and Tubercula Quadrigemina into the anterior and antero-lateral columns of the Spinal Cord; in its course it gives-off the

roots of all the motor nerves usually considered as cranial; and greater part of its fibres undergo decussation below the Pons Varolii. —The functions of the Medulla Oblongata are, therefore, of a double character; to bring the higher parts of the Encephalon into connection with the Spinal Cord and its nerves; and to serve as a centre for the reflex movements, performed through the nerves that issue from itself. In both respects it corresponds precisely with any segment of the proper Spinal Cord; and there is no reason to believe that it possesses any other or more special endowments. The importance, however, of the reflex acts of Respiration and Deglutition, of which it is the centre, causes this portion of the Medulla to be the one whose integrity is most essential to the preservation of life; and therefore it *seems* to possess a character more distinctive than it really has.

Fig. 167.*



895. The chief *excitor* nerve of the *Respiratory* movements, as already stated (§§ 685—687) is the afferent portion of the Par Vagum; but the afferent portion of the Fifth pair is also a powerful excitor; and the afferent portions of all the Spinal nerves, conveying impressions from the general surface of the body, are also

* Dissection of the Medulla Oblongata, to show the connections of its several strands:—A, corpus striatum; B, thalamus opticus; C, D, corpora quadrigemina; E, commissure connecting them with the cerebellum; F, corpora restiformia; P, P, pons varolii; *st*, *st*, sensory tract; *mt*, *mt*, motor tract; *o*, olivary tract; *p*, pyramidal tract; *og*, olivary ganglion: *op*, optic nerve; 3*m*, root of the third pair (motor); 5*s*, sensory root of the fifth pair.

capable of contributing to the excitement necessary for the production of the movement.—The chief *motor* nerves are the Phrenic and Intercostals; which, though issuing from the Cord at a considerable space lower down, probably originate in the Medulla Oblongata. The motor portions of several other spinal nerves are also partly concerned; as are also the Facial nerve, the motor portion of the Par Vagum, and the Spinal Accessory. The ordinary movements of Respiration involve little action of any motor nerves but the phrenic and intercostal; and it is only when an excess of the stimulus (produced, for example, by too long a suspension of the aerating process) excites *extraordinary* movements, that the nerves last enumerated are called into action.

896. The acts of *Prehension* of food with the lips, and of *Mastication*, though usually effected by voluntary power in the adult, seem to be capable of taking-place as a part of the reflex operation of the Medulla Oblongata, in the Infant, as in the lower animals. This is particularly evident in the prehension of the nipple by the lips of the infant, and in the act of suction which the contact of that body (or of any resembling it) seems to excite. The experiments provided for us by nature, in the production of anencephalous monstrosities, fully prove that the integrity of the nervous connection of the lips and respiratory organs with the Medulla Oblongata, is alone sufficient for the performance of this action; and experiments upon young animals from which the brain has been removed, establish the same fact. Thus Mr. Grainger found that upon introducing his finger moistened with milk or with sugar and water between the lips of a puppy thus mutilated, the act of suction was excited; and not merely the act of suction itself, but other movements having a relation to it; for as the puppy lay on its side, sucking the finger, it pushed-out its feet, in the same manner as young pigs exert theirs in compressing the sow's dugs. This action seems akin to many of those by which the lower animals take-in their food; and we may thus recognize in the Medulla Oblongata a distinct centre of reflex action for the reception and deglutition of aliment, analogous to the *stomato-gastric* ganglia of Invertebrated animals.

897. In the movements of *Deglutition*, which, as formerly explained (§ 453), are purely reflex, the chief *excitor* is undoubtedly the afferent portion of the Glosso-pharyngeal nerve. It is found that if the trunk of this nerve, or its pharyngeal (but not its lingual) branches, be pinched, pricked, or otherwise irritated, whilst still in connection with the Medulla Oblongata, the movements concerned in the act of swallowing are excited. The same occurs if, when the trunk of the Glosso-pharyngeal has been divided, the cut extremity in connection with the Medulla Oblongata be irritated; but little or no muscular contraction is produced by irritation of the separated extremity; whence it is apparent that

the Glosso-pharyngeal has little or no direct motor power, but acts as an excitor. In this it appears to be assisted by the branches of the Fifth pair distributed upon the fauces; and probably, also, by the branches of the superior laryngeal distributed upon the pharynx. The motor influence which is generated in respondence to the stimulus thus conveyed, appears to act chiefly through the branches of the Par Vagum, which are distributed to most of the muscles concerned in swallowing; but the Facial, the Hypoglossal, the motor portion of the Fifth, and perhaps also the motor portions of some of the Cervical nerves, are also concerned in the movement, and can effect it, though with difficulty, after the pharyngeal branches of the Par Vagum have been divided.

898. In the propulsion of the food down the Œsophagus, to which the glosso-pharyngeal nerve does not extend, the muscular contraction, so far as it is of a reflex nature (§ 455), must depend upon the œsophageal branches of the Par Vagum alone; their afferent portion being the excitor, and their motor portion giving the requisite stimulus to the muscles. The same must be the case in regard to the muscular contractions of the cardiac and pyloric sphincters, and of the walls of the Stomach, so far as regards their dependence upon the nervous system at all; but the degree of this is doubtful.

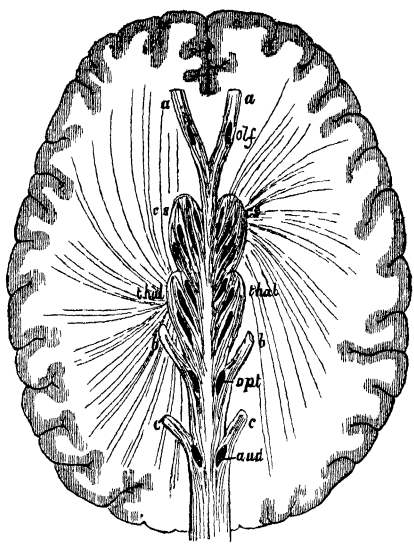
899. There are other reflex actions of the Medulla Oblongata, connected with the regulation of the aperture of the Glottis; these, which are effected through the superior and inferior laryngeal branches of the Par Vagum, will be better noticed when the actions of the Larynx are under consideration (§ 976).—In like manner, the reflex action concerned in the regulation of the aperture of the Pupil will be more conveniently noticed in the sketch to be hereafter given of the Physiology of Vision (§ 969).

5. *Functions of the Sensory Ganglia.*

900. All the nerves of sensation, both *general* and *special*, may be traced into a series of ganglionic masses lying at the base of the brain; which seem to constitute their own particular centres. Thus we have seen in Fishes, the Olfactive, Optic, and Auditory ganglia, marked-out as such by the termination of the nerves proceeding from the organs of smell, sight, and hearing, in these masses respectively. These ganglia bear an evident correspondence with the cephalic ganglia of the Invertebrata; which must chiefly, however, be regarded as *optic* ganglia, since the development of the eyes far surpasses that of the other organs of special sense. On the other hand, they find their representatives in certain organs at the base of the brain, in Man and the higher Mammalia (Fig. 168); which, though small in proportion to the whole Encephalon, are capable of being clearly marked-out as the ganglionic

centres of the several nerves of sense.—Thus, anteriorly, we have the *Olfactive* ganglia, in what are commonly termed the bulbous

Fig. 168.*



expansions of the Olfactive nerve; which, however, are real ganglia, containing grey or vesicular substance; and their separation from the general mass of the Encephalon, by the peduncles or footstalks commonly termed the trunks of the olfactory nerves, finds its analogy in many species of Fish (§ 869). The ganglionic nature of these masses is more evident in many of the lower Mammalia, in which the organ of smell is highly developed, than it is in Man, whose olfactive powers are comparatively moderate.—At some distance behind these we have the representatives of the *Optic* Ganglia, in the *Tubercula Quadrigemina*, to which the principal part of the roots of the Optic nerve may be traced. Although these bodies are

* Diagram of the relation of the Sensori-motor tract at the base of the Brain, to the Cerebrum, as seen in horizontal section:—*olf*, olfactive ganglia; *opt*, optic ganglia; *aud*, auditory ganglia; *cs*, corpora striata; *thal*, thalami optici; *a*, *a*, olfactive nerves; *b*, *b*, optic nerves; *c*, *c*, auditory nerves.

so small in Man as to be apparently insignificant, yet they are relatively larger, and form a more evidently-important part of the Encephalon, in many of the lower Mammalia; though still presenting the same general aspect.—The *Auditory* ganglia seldom form distinct lobes or projections; but are usually lodged in the substance of the Medulla Oblongata. Their real character is most evident in certain Fishes, as the Carp, in which we find the Auditory nerve having as distinct a ganglionic centre as the Optic. In higher animals, however, we are able to trace the Auditory nerve into a small nucleus of grey matter which lies on each side of the Fourth Ventricle; and although this is lodged in the midst of parts whose function is altogether different, yet there seems no reason for doubting that it has a character of its own, and that it is really the ganglion of the auditory nerve.—We are not able to fix upon any such mass of grey matter as the distinct *Gustatory* ganglion; nor is it necessary to attempt to do so, for, as we shall see hereafter, we may regard the sense of Taste as a modification of that of Touch.

901. At the base of the Cerebral Hemispheres, we find two ganglionic masses on either side, through which all the fibres pass that connect the Hemispheres with the Medulla Oblongata. These are the *Corpora Striata*, and *Thalami Optici*. Upon tracing forwards the tract of motor fibres that ascend from the Anterior Pyramids, we find it passing chiefly into the Corpora Striata: whilst if we follow the Sensory column that ascends from the Posterior Pyramids, we shall find it to enter the Thalami Optici. These bodies have been usually considered as mere appendages to the Cerebrum; but the fact that they are independent centres of action, is fully established by the presence of a large quantity of vesicular matter in their substance; and there is now a sufficiently large amount of evidence, both anatomical and physiological, to render it probable that the fibres which seem to pass through them from the Crura Cerebri, and then to radiate towards the periphery of the Cerebral Hemispheres, do not do so in reality; but that these ganglionic masses receive, on the one hand, the fibres that ascend to them from the Medulla Oblongata, and, on the other, are the point of departure of a new set that passes to the proper Cerebrum. Looking to the connection of the Thalami Optici with the sensory tract, they may be not improbably considered as the ganglionic centres of *common* sensation; standing in the same relation to the sensory nerves that converge from various parts of the body towards the Encephalon, as do the Optic and other ganglia to their nerves of *special* sensation. And as these last give origin to motor fibres, so may we regard the ganglionic matter of the Corpora Striata (which are in close connection with the Thalami) as probably sharing in the same function; giving origin to the motor fibres, which produce the respondent consensual movements; just as the

anterior peak of grey matter in the Spinal Cord gives exit to the motor filaments, which effect the reflex movements excited through the afferent fibres forming part of the posterior roots.

902. The functions of this series of ganglia may be more certainly determined by the aid of Comparative Anatomy, than by experimental mutilations. Reverting to the class of Fishes, we find that it there constitutes (with the Cerebellum) nearly the entire Encephalon; scarcely a rudiment of the true Cerebrum being discoverable in that group.* And when we descend to the Invertebrata, we find the cephalic masses entirely to consist of the ganglionic centres of the nerves of sense and motion. There can scarcely be a reasonable doubt, that these Cephalic ganglia are the seat of consciousness and the sources of those movements which are directed by sensation, in such animals as present this low type of nervous organization; and there is no adequate reason for the belief, that the superaddition of the Cerebral Hemispheres in the Vertebrated series *alters* the endowments of the Sensory Ganglia on which they are superimposed; on the contrary, we everywhere see that the addition of new ganglionic centres, as instruments of new functions, leaves those which were previously existing in the discharge of their original duties. Hence we should be led to regard them as the centres of consciousness, even in Man, each pair of ganglionic centres ministering to that peculiar kind of sensation for which its nerves and the organs they supply are set apart; thus we should consider the Optic ganglia to be the seat of visual sensations, the Auditory to be the seat of the sense of hearing, and so on. And we should also consider them as the instruments whereby sensations, of whatever kind, either originate or direct *Automatic* movements.

903. So far as the results of experiments can be relied-on, they afford a confirmation of these views, by showing that sensory impressions can be felt, and that automatic movements of a higher kind than the simply-reflex can be called into play, after the removal of the Cerebral Hemispheres, provided that these ganglia be left intact. Thus if a Bird be thus mutilated, it maintains its equilibrium, and recovers it when it has been disturbed; if pushed, it walks; if thrown into the air, it flies. A pigeon deprived of its cerebrum has been observed to seek-out the light parts of a partially illuminated room in which it was confined, and to avoid objects that lay in its way; and at night, when sleeping with closed eyes and its head under its wing, it raised its head and opened its eyes upon the slightest noise.—So, again, the removal or destruction of one pair of these Sensory centres, appears to involve the loss of the particular sense to which it ministers; and frequently, also, to

* The ganglionic masses that are commonly designated as the *Cerebral* lobes or hemispheres, must be really likened in great part (as already stated § 869) to the Corpora Striata.

occasion such a disturbance in the ordinary movements of the animal, as to show the importance of these centres in regulating them. Such experiments have been chiefly made upon the *Optic* ganglia, or Corpora Quadrigemina; the partial loss of which on one side produces temporary blindness in the eye of the opposite side, and partial loss of muscular power on the opposite side of the body; whilst the removal of a larger portion, or the complete extirpation of it, occasions permanent blindness and immobility of the pupil, and temporary muscular weakness, on the opposite side. This temporary disorder of the muscular system sometimes manifests itself in a tendency to move on the axis, as if the animal were giddy; and sometimes in irregular convulsive movements.—Here, then, we have proof of the necessity of the integrity of this ganglionic centre, for the possession of the sense of vision; and we have further proof that the ganglion is connected with the muscular apparatus, by motor nerves issuing from it. The reason why the eye of the *opposite* side is affected, is to be found in the *decussation* of the optic nerves, a point to be immediately adverted-to (§ 907). The influence of the operation on the muscles of the *opposite* side of the body, is at once understood from the fact of the decussation of the motor fibres in the anterior pyramids (§ 890).—Similar disturbances of movement have been produced, by injuries to the organs of sense themselves, or to the nerves connecting them with the sensorial centres. Thus if one of the eyes of a pigeon be blindfolded, or its humours be evacuated, vertiginous motions ensue; and section of one of the semicircular canals of the ear in pigeons and rabbits has been found to occasion constant efforts to move in the plane of that canal, thus confirming the belief that the function of these canals is to indicate the direction of sounds (§ 952).

904. Notwithstanding that, in Man, the high development of *Intelligence*, and the exercise of the *Will*, supersede in great degree the operations of *Instinct*, we still find that there are in ourselves certain movements which can be distinguished as neither voluntary nor excito-motor, and which are examples of the method of operation that seems to be the chief source of the actions of the lower Vertebrata, as of the Invertebrated classes in general. These movements are as automatic and involuntary as are the ordinary reflex actions, but differ from them in requiring that the impressions which originate them should be *felt* as sensations; and hence they are conveniently designated as *consensual*.—As examples of this group, we may advert to the start upon a loud and unexpected sound; the sudden closure of the eyes to a dazzling light, or on the approach of bodies that might injure them, which has been observed to take-place even in cases in which the eyelids could not be voluntarily closed; the act of sneezing excited by an irritation of the nostril, and sometimes also by a dazzling light; the semi-convulsive movements and the laughter called forth by tickling; and the

vomiting occasioned by the sight or the smell of a loathsome object. So, again, the act of yawning is ordinarily called-forth by certain uneasy sensations within ourselves, but also by the sight or hearing of the act as performed by another. Various phenomena of disease exhibit the powerful influence of sensations in producing automatic motions; as instances of this kind, we may refer to the effects of the sight or the sound of liquids, or of the slightest currents of air, in exciting the Hydrophobic paroxysm; whilst in many Hysteric subjects the sight of a paroxysm in another individual is the most certain means of its induction in themselves.—The most remarkable examples, however, of automatic movements depending upon sensations, are those which we come to perform *habitually*, and as we commonly say *mechanically*, when the attention and the voluntary effort are directed in quite a different channel. Thus the man who is walking through the streets in a complete reverie, unravelling some knotty subject, or working-out a mathematical problem, not only performs the movements of progression (which may be excito-motor) with great regularity, but also directs these in a manner which plainly indicates the guidance of sensations. For he will avoid obstacles in the line of his path, and he will follow the course which he has been accustomed to take, although he may have intended to pass along some very different route; and it is not until his attention is recalled to his situation, that his train of thought suffers the least intermission, or that his will is brought to bear upon his motions.

905. We may trace the agency of the Sensory Ganglia, however, in the Human subject, not merely in their direct and independent operation upon the muscular system, but also in the manner in which they participate in all Voluntary actions. The existence of a Sensation of some kind, in connection with Muscular exertion, seems essential to the continuance of the latter. Our ordinary movements are guided by what is termed the *Muscular Sense;* that is, by a feeling of the condition of the muscle, that comes to us through its own sensory nerves. How necessary this is to the exercise of muscular power, may be best judged-of from cases in which it has been lost. Thus a woman who had suffered complete loss of sensation in one arm, but who retained its motor power, found that she could not support her infant upon it without constantly *looking* at the child; and that, if she were to remove her eyes for a moment, the child would fall, in spite of her knowledge that her infant was resting upon her arm, and of her desire to sustain it. Here, the muscular sense being entirely deficient, the sense of vision supplied what was required, so long as it was exercised upon the object; but as soon as this guiding influence was withdrawn, the strongest will could not sustain the muscular contraction.—Again, in the production of vocal sounds, the nice adjustment of the muscles of the larynx, which is requisite to

produce determinate tones, can only be effected in obedience to a mental conception of the tone to be uttered; and this conception cannot be formed unless the sense of hearing has previously brought similar tones to the mind. Hence it is that persons who are born *deaf* are also *dumb*. They may have no malformation of the organs of speech; but they are incapable of uttering distinct vocal sounds or musical tones, because they have not the guiding conception or recalled sensation of the nature of these. By long training, and by efforts directed by the muscular sense of the larynx itself, some persons thus circumstanced have acquired the power of speech; but the want of sufficiently-definite control over the vocal muscles, is always very evident in their use of the organ.

906. Quitting now the functions of the Sensory Ganglia, we have briefly to notice certain peculiarities in the characters of the Nerves to which they serve as the centres. And of these peculiarities, there is one of a very remarkable nature, which is common to the three nerves of *special* sense,—namely, the Olfactive, Optic, and Auditory;—that they are not in the least degree endowed with *common* sensibility; so that they may be cut, stretched, pinched, &c., without producing the least pain. Consequently, the ordinary sensibility of the surfaces they supply is entirely due to the branches of the Fifth pair which are distributed upon them; and we may have a loss of either the *general* or the *special* sensibility of any of the organs of sense, without the other being affected, save indirectly. —Again, we do not find that irritation of these nerves produces any other purely *reflex* movements, than such as are connected with the operations of the organs of sense in which they respectively originate. Thus the Olfactory nerve cannot, by any irritation, be made to excite a reflex movement; the only reflex action that can be excited by irritating the Optic nerve, is contraction of the Pupil; and the regulation of the tension of the Membrana Tympani (if, as is probable, this be effected by the motor power of the Facial nerve, excited by impressions made upon the organ of sense) appears to be the only reflex action to which the Auditory nerve can minister.

907. There is a further peculiarity, of a very marked kind, attending the course of the *Optic* nerves; this is the crossing or decussation which they undergo, more or less completely, whilst proceeding from their ganglia to the eyes. In some of the lower animals, in which the two eyes (from their lateral position) have entirely different spheres of vision, the decussation is complete; the whole of the fibres from the right Optic ganglion passing into the left eye, and *vice versâ*. This is the case, for example, with most of the Osseous Fishes (as the cod, halibut, &c.); and also, in great part at least, with Birds. In the Human subject, however, and in animals which, like him, have the two eyes looking in the same direction, the decussation seems less complete; but there is a

very remarkable arrangement of the fibres, which seems destined to bring the two eyes into peculiarly consentaneous action. The *posterior* border of the Optic Chiasma is formed exclusively of *commissural* fibres, which pass from one *optic ganglion* to the other, without entering the real optic nerve. Again, the *anterior* border of the chiasma is composed of fibres, which seem, in like manner, to act as a commissure between the two *retinæ;* passing from one to the other, without any connection with the optic ganglia. The tract which lies between the two borders, and occupies the *middle* of the chiasma, is the true optic nerve; and in this it would appear that a portion of the fibres decussates, whilst another portion passes directly from each Optic ganglion into the corresponding eye. The fibres which proceed from the ganglia to the retinæ, and constitute the proper optic nerves, may be distinguished into an internal and an external tract. Of these, the *external*, on each side, passes directly onwards to the eye of *that* side; whilst the internal crosses over to the eye of the *opposite* side. The distribution of these two sets of fibres in the retina of each eye respectively, is such that, according to Mr. Mayo, the fibres from either optic ganglion will be distributed to *its own side* of *both* eyes;—the right optic ganglion being thus exclusively connected with the outer part of the retina of the right eye, and with the inner part of the retina of the left eye; and the left optic ganglion being, in like manner, connected exclusively with the outer side of the left retina, and with the inner side of the right. Now as either side of the eye receives the images of objects which are on the other side of its axis, it follows, if this account of their distribution be correct, that in Man, as in the lower animals, each ganglion receives the sensations of objects situated on the *opposite* side of the body. The purpose of this decussation may be, to bring the visual impressions, which are so important in directing the movements of the body, into proper harmony with the motor apparatus; so that, the decussation of the motor fibres in the pyramids being accompanied by a decussation of the optic nerves, the same effect is produced as if neither decussated,—which last is the case with Invertebrated animals in general.

6. *Functions of the Cerebellum.*

908. Much discussion has taken-place, of late years, respecting the uses of the Cerebellum; and many experiments have been made to determine them. That it is in some way connected with the powers of *motion*, might be inferred from its connexion with the antero-lateral columns of the Spinal Cord, as well as with the posterior; and the comparative size of the organ, in different orders of Vertebrated animals, gives us some indication of what the nature of its function may be. For we find its degree of development to correspond pretty closely with the variety and energy of the mus-

cular movements which are habitually executed by the species; the organ being the largest in those animals which require the *combined* effort of a great variety of muscles to maintain their usual position, or to execute their ordinary movements; whilst it is the smallest in those which require no muscular exertion for the one purpose, and little combination of different actions for the other. Thus in animals that habitually rest and move upon four legs, there is comparatively little occasion for any organ to combine and harmonise the actions of their several muscles; and in these, the Cerebellum is usually small. But among the more active predaceous Fishes (as the Shark), Birds of the most powerful and varied flight (as the Swallow), and such Mammals as can maintain the erect position, and can use their extremities for other purposes than support and motion,—we find the Cerebellum of much greater size, relatively to the remainder of the Encephalon. There is a marked advance in this respect, as we ascend through the series of Quadrumanous animals; from the Baboons which usually walk on all-fours, to the semi-erect Apes which often stand and move on their hind-legs only. The greatest development of the Cerebellum is found in Man; who surpasses all other animals in the number and variety of the combinations of muscular movement which his ordinary actions involve, as well as of those which he is capable, by practice, of learning to execute.

909. From experiments upon all classes of Vertebrated animals, it has been found that, when the Cerebellum is removed, the power of walking, springing, flying, standing, or maintaining the equilibrium of the body, is destroyed. It does not seem that the animal has in any degree lost the *voluntary* power over its individual muscles; but it cannot *combine* their actions for any general movements of the body. The *reflex* movements, such as those of respiration, remain unimpaired. When an animal thus mutilated is laid on its back, it cannot recover its former posture; but it moves its limbs, or flutters its wings, and evidently is not in a state of stupor. When placed in the erect position, it staggers and falls like a drunken man; not, however, without making efforts to maintain its balance. Phrenologists, who attribute a different function to the Cerebellum, have attempted to put aside these results, on the ground that the severity of the operation is alone sufficient to produce them; but, as we have already seen (§ 903), many animals may be subjected to a much more severe operation, the removal of the Cerebral hemispheres, without the loss of the power of combining and harmonizing the muscular actions, provided the Cerebellum be left uninjured.—Thus, then, the idea of the functions of the Cerebellum which we derive from Comparative Anatomy, seems fully borne-out by the results of experiment; and it is also consistent with the indications which may be drawn from the observations of Pathological phenomena. When the Cerebellum is affected with

chronic disease, the motor function is seldom destroyed; but the same kind of want of combining power shows itself, as when the organ has been purposely mutilated. Some kind of lesion of the motor function is invariably to be observed; whilst the mental powers may or may not be affected,—probably according to the influence of the disease in the Cerebellum upon other parts. The same absence of any direct connection with the Psychical powers, is shown in the fact that inflammation of the membranes covering it, if confined to the Cerebellum, does not produce delirium. Sudden effusions of blood into its substance may produce apoplexy or paralysis; but this may occur as a consequence of effusions into *any* part of the Encephalon, and does not indicate that the Cerebellum has anything to do with the mental functions, or with the power of the Will over the muscles.

910. There is another doctrine, however, in regard to the functions of the Cerebellum, first propounded by Gall; which ought not to be altogether passed-by. According to the system of Phrenologists, the Cerebellum is the organ of the sexual instinct; and its connection with the motor function is limited to the performance of the movements to which that instinct leads. This doctrine derives no support, however, from the facts supplied by Comparative Anatomy; for there is a complete want of correspondence between the size of the Cerebellum in different animals, and the power of their sexual instinct.—Again, although Pathology has been appealed to, as showing a decided connection between disease of the Cerebellum and affection of the Genital organs (manifesting itself in priapism, turgescence of the testes, seminal emissions, &c.), yet it appears, on a careful examination of the evidence, that such a sympathy is comparatively rare, not being displayed in more than one out of every seventeen cases of Cerebellic disease. And where it is manifested, it is explicable quite readily by the known fact, that this kind of excitement of the genital organs may be produced by excitement of the spinal cord and medulla oblongata.—Little or no light has been thrown on this question by experiment. It was asserted by Gall, that the Cerebellum is very small in castrated animals; but this assertion has been met by the most positive counter-statements on the part of Leuret, who has shown that the average weight of the Cerebellum (both absolutely and in proportion to the weight of the entire encephalon) is even greater in Geldings, than in Stallions or Mares.—It is asserted, however, that the results of observation in Man lead to a positive conclusion, that the size of the Cerebellum is a measure of the intensity of the sexual instinct in the individual. This assertion has been met by the counter-statement of others, that no such relation exists. There are, of course, very great difficulties in regard to the collection of accurate information on this subject; and the question must be at present regarded as *sub judice*.

911. The idea of a special connection between the sexual instinct and the Cerebellum, however, is not inconsistent with the view of its function previously stated; and it would seem to derive some confirmation from the fact, that an unusual amount of muscular exertion appears to have a peculiar tendency to depress the sexual passion, even whilst it increases the general vigour of the system. If the Cerebellum be really connected with both kinds of functions, it does not seem unlikely that the excessive employment of it upon one, should diminish its energy in regard to the other. Further, it seems not improbable that the *lobes* of the Cerebellum may be the parts specially concerned in the regulation of the muscular movements; whilst the central portion (constituting the Vermiform process in Man, but forming the entire cerebellum of many of the lower Vertebrata, such as the Frog) may contain the centre of the sexual sensations, and may thus be the instrument of the consensual actions to which they give rise. And a careful examination of the pathological phenomena which bear upon the question, seems to favour this supposition.

7. *Functions of the Cerebrum.*

912. The view which has been taken of the Comparative structure of the Nervous system in different animals, leads to the conclusion that the Cerebral Hemispheres are far from being the essential parts of the apparatus they were formerly imagined to be; and that they are, on the contrary, superadded organs, of which we find no distinct representatives in the Invertebrata, and of which the first appearance (in the class of Fishes) exhibits them in the light of appendages destined to perform some special function peculiar to Vertebrated animals. The results of the removal of the Cerebral Hemispheres, in animals to which the shock of the operation does not prove immediately fatal, fully confirm this view; and must appear extraordinary to those who have been accustomed to regard these organs as the centre of all energy. Not only Reptiles, but Birds and Mammals, if their physical wants be supplied, may survive the removal of the whole Cerebrum for weeks or even months. If the entire mass be taken away at once, the operation is usually fatal; but if it be removed by successive slices, the shock is less severe, and the depression it produces in the organic functions is soon recovered-from. It is difficult to substantiate the existence of actual sensation, in animals thus circumstanced; but their movements appear to be of a higher kind, as already remarked (§ 903), than those resulting from mere reflex action. Thus they will eat food, when it is put into their mouths; although they do not go to seek it. If violently aroused, the animal has all the manner of one waking from sleep; and it manifests about the same degree of consciousness with a sleeping Man, whose torpor is not

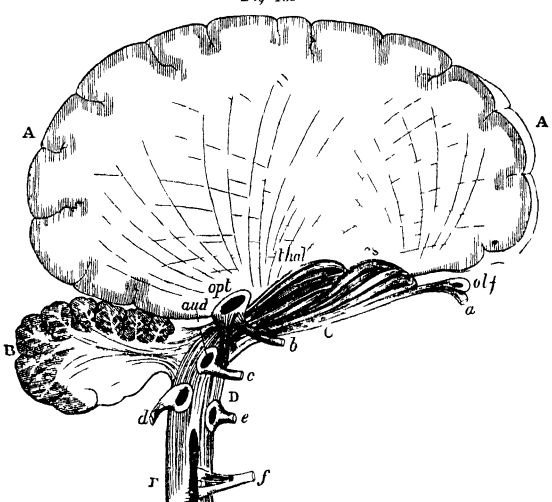
too profound to prevent his suffering from an uneasy position, and who moves himself to amend it. In both cases, the movements are *consensual* only, and do not indicate any intelligence or voluntary power; and we may well believe that, in the former case as in the latter, though *felt* they are not *remembered;* an active state of the Cerebrum being essential to *memory*, though not to sensations, which simply excite certain actions.—When the Cerebral Hemispheres are being removed, slice by slice, it is noticed that injuries of these organs neither occasion any signs of pain, nor give rise to convulsive movements. Even the Thalami and Corpora Striata may be wounded, without the excitement of convulsions; whilst, if the incisions involve the Tubercula Quadrigemina, convulsions uniformly occur. It has been often observed in Man, that, when it has been necessary to separate a protruded portion of the brain from the healthy part, no sensation was produced, even though the mind was perfectly clear at the time. Hence it would appear that neither is the Cerebrum itself the centre of sensation, nor is it so connected with that centre, as to be able to convey to it sensory impressions of an *ordinary* kind. This is analogous to the condition of the nerves of *special sense*, as already remarked. That no irritation of the cerebral substance should excite convulsive movements, is a very remarkable circumstance; and it seems to indicate, that the changes which *mental* operations produce in the cerebral fibres, cannot be imitated, as changes in other motor fibres may be, by physical impressions.

913. As already stated, the relative amount of *Intelligence* in different animals bears so close a correspondence with the relative size and development of the Cerebral Hemispheres, that it can scarcely be questioned that these constitute the organ of the reasoning faculties, and issue the mandates by which the Will calls the muscles into action. It must be borne in mind, however, that *size* is not by any means the only indication of their comparative development. As we advance from the lower to the higher Vertebrata, we observe a marked advance in the complexity of the structure of the Cerebrum. Its surface becomes marked by convolutions, that greatly increase the area over which blood-vessels can enter it from the surrounding membranes; and in proportion to the increase in the number and depth of these, do we find an increase in the thickness of the layer of *grey* matter. which is the source of all the powers of the organ. The arrangement of the white or fibrous tissue, which forms the interior of the mass, also increases in complexity; and as we ascend even from the lower Mammalia up to Man, we trace a marked increase in the number of the fibres which establish communications between different parts of the organ. It is, in fact, not merely from the different parts of the grey matter which forms the *surface* of the hemispheres, that these commissural fibres arise, but also from those isolated portions of

vesicular substance which are found in different parts of their interior, and an extremely complex system is thus formed, which is still but very imperfectly understood

914 The most important group of commissural fibres, is that which connects the *Sensory* with the *Hemispheric* Ganglia, that is, which radiates from the Thalami Optici and Corpora Striata, to the stratum of grey matter which forms the convoluted surface of the Cerebrum These fibres constitute, in fact, the principal part of the white substance of the brain, the remainder being made up by the commissures to be presently described, and by commissural fibres which (it is probable) connect the different parts of the Cerebral surface with each other It was formerly supposed (and is still maintained by many Anatomists), that the radiating fibres

Fig 169 *



* Diagram of the mutual relations of the principal Encephalic centres as shown in a vertical section —A, Cerebrum B Cerebellum C Sensori motor tract, including the Olfactive ganglion *olf*, the Optic *opt* and the Auditory *aud*, with the Thalami Optici *thal*, and the Corpora Striata *cs* D Medulla Oblongata, E, Spinal Cord,—*a*, olfactive nerve *b* optic *c* auditory *d*, pneumogastric *e*, hypoglossal, *f*, spinal fibres of the medullary substance of the Cerebrum are shown, connecting its ganglionic surface with the sensori motor tract

which may be traced from the surface of the Cerebrum to the Corpora Striata and Thalami Optici, *pass through* these bodies, so as to become continuous with the Crura Cerebri, and consequently with the sensory and motor tracts of the Medulla Oblongata. But when the small size of the crura cerebri is compared with the relatively-enormous bulk of the radiating fibres, it is obvious that the former can only contain but a very small proportion of the latter; and as no absolute continuity has been traced, it appears more conformable to Anatomical and Physiological probability, to believe that the fibres of the Crura Cerebri pass no further upwards than the Sensory Ganglia, and that the radiating fibres take a fresh departure from these bodies, to pass towards the surface of the Cerebrum.—Thus, then, we should be led to regard the Spinal Cord, Medulla Oblongata, and chain of Sensory Ganglia, as precisely representing the entire Nervous System of Insects, the character of whose action is essentially *automatic;* and to consider the Cerebrum as an organ superadded to its summit, receiving all its incitement to action from impressions transmitted to it through the Sensory Ganglia, and carrying into effect its volitional determinations and its ideational and emotional impulses, not (as formerly supposed) by immediately exciting muscular movements through nervous communications passing direct from the convoluted surface of the Cerebrum, but by playing downwards upon the Automatic apparatus by which its mandates are carried into effect (Figs. 168, 169). Of this view we shall presently find that there is strong physiological evidence (§ 923).

915. The two Hemispheres are united on the median line by several *transverse* commissures; of which the *Corpus Callosum* is the most important. This consists of a mass of fibres very closely interlaced together; which may be traced into the substance of the hemispheres on each side, particularly at their lower part, where they are connected with the thalami optici and corpora striata. It is difficult, if not impossible, to trace its fibres any further; but there can be little doubt that they radiate, with the fibres proceeding from the bodies just named, to the different parts of the surface of the hemispheres. This commissure is altogether absent in Fish, Reptiles, and Birds; and it is partially or completely wanting in the Mammals with least perfect brain, as the Rodents and Marsupials. —The other transverse commissures rather belong to the Sensory Ganglia than to the Cerebral Hemispheres. Thus the *anterior* commissure particularly unites the Corpora Striata of the two sides; but many of its fibres pass through these organs, and radiate towards the convolutions of the hemispheres, especially those of the middle lobe. This commissure is particularly large in those Marsupials, in which the corpus callosum is deficient.—The *posterior* commissure is a band of fibres which connects the Optic Thalami, crossing-over from the posterior extremity of one to that of the

other.—Besides these, there are other groups of fibres which seem to have similar commissural functions, but which are intermingled with vesicular substance. Such are the *soft* commissure, which also extends between the thalami; the Pons Tarini, which extends between the two crura or peduncles of the Cerebrum; and the Tuber Cinereum, which seems to unite the optic tracts with the thalami, the corpus callosum, the fornix, &c., and to be a common point of meeting for several distinct groups of fibres.

916. The anterior and posterior parts of the hemispheres, moreover, are connected by *longitudinal* Commissures, of which some lie above, and some below, the corpus callosum; and of these, also, a part belong to the Sensory Ganglia. Above the transverse fibres of the corpus callosum, there is a longitudinal tract on each side of the median line, which serves to connect the convolutions of the anterior and posterior lobes of the brain.—And above this, again, is the *superior longitudinal commissure*, which is formed by the fibrous matter of the great convolution nearest the median plane on the upper surface of the brain, and which connects the convolutions of the anterior and middle lobe with those of the posterior.—Beneath the great transverse commissure, we find the most extensive of all the longitudinal commissures, namely, the *fornix*. This is connected in front with the optic thalami, the mammillary bodies, the tuber cinereum, &c.; and behind, it spreads its fibres over the hippocampi (major and minor), which are nothing else than peculiar convolutions that project into the posterior and descending cornua of the lateral ventricles.—The fourth longitudinal commissure is the *tænia semicircularis*, which forms part of the same system of fibres with the fornix; connecting the corpus mammillare and thalamus opticus of each side with the middle lobe of the cerebral hemisphere.—If, as Dr. Todd has remarked, we could take away the corpus callosum, the grey matter of the internal convolution, and the ventricular prominence of the optic thalami, then all these commissures would fall together, and become united as one and the same series of longitudinal fibres.—It is curious that there should be no direct communication between the Cerebral hemispheres and the Cerebellum; the only commissural band between them being the *processus a cerebello ad testes*, which passes onwards, through the tubercula quadrigemina, to the thalamus opticus on each side. This would seem to confirm the idea of the complete distinctness of their functions.

917. The Cerebrum appears to be the instrument of all those psychical operations, which are superadded, in Man and the higher Vertebrata, to mere sensations. The impressions which are merely *felt* in the sensorium, give rise, when they pass upwards into the Cerebrum, to *Ideas*, which then become the material (so to speak) of all the higher mental processes. These processes may be ranked under two distinct heads, namely, the *Emotional* and the *Intelli-*

gential; the former being most intimately connected with the sensations which prompt them, whilst the latter are commonly of a much more abstract character. The Emotions may, in fact, be considered as *feelings*, mostly of pleasure or pain, associated with particular classes of ideas; and it is this association which gives them the character of the moving or active powers of the mind, and which makes them, either directly or indirectly, the springs of the greater part of our actions. When strongly excited, the Emotions may produce movements which the Will may not be able to restrain; as when we burst into laughter at some ludicrous image presented to the mind, either by a present sensation or by an act of the memory or imagination, notwithstanding the strongest inducements presented by 'time, place, and circumstance' to a preservation of our gravity. The distinctness of the character of Emotional and Volitional movements is further evident from this, that cases of paralysis not unfrequently occur (especially in the facial nerve, through which most of the muscles of 'expression' are excited to action), in which the muscles are obedient to one class of impulses, while the other exerts no power over them. Thus, in one instance, the muscles of one side of the face were palsied in such a manner, that the patient could not voluntarily close his eye nor draw his mouth towards that side; yet when any ludicrous circumstance caused him to laugh, their usual play was manifested in the expression of his countenance. And in another case, the muscles were obedient to the Will; but when the individual laughed or cried under the influence of an emotion, it was only on one side of his face. To these may be added another case, in which the right arm was completely palsied, so that the individual had not the least voluntary power over it; yet it was violently agitated, whenever he met a friend whom he desired to greet.—The influence of an undue tendency to Emotional excitement, is remarkably seen in what are ordinarily termed *Hysterical* states of the system; in which violent convulsive paroxysms are frequently brought-on by the most trivial causes, if these should call the passions or affections of the mind into undue activity. There can be no doubt that many of the peculiar actions performed by the subjects of what is termed Mesmeric influence, are the result of a condition of this nature. There appears to be, in such persons, a proneness to activity of the consensual and emotional parts of the nervous centres, which manifests itself most strongly when the control of the will is withdrawn; and thus very slight impressions produce very powerful involuntary movements,—especially when this response is favoured by the strong desire, on the part of the patient, to exhibit any particular manifestation that is known to be expected by the bystanders.

918. It has been supposed by some, that the *Emotional* movements of Man and the higher animals may be ranked in the same category with the *Instinctive* actions of the lower; and that the

Desires of the former are comparable to the instinctive *Propensities* of the latter. But this comparison is erroneous; for what we term propensities (among the lower animals) are nothing else than tendencies to perform particular movements in respondence to particular sensations, without any *idea* of the purpose of the movement, or of the object which has excited it; whilst an Emotion involves an idea of the object which has called it up, and a Desire involves a conception of the object to be attained.—The *imitative* actions afford a good example of the difference between a propensity and a desire. The propensity to involuntary imitation, which is much stronger in some individuals than in others, is manifested in such imitative movements as are purely consensual; the sensation, which is the mainspring of the action in each case, exciting a respondent automatic movement, as when we yawn involuntarily from seeing or hearing the action performed by another, or as when children learn undesignedly to perform many of the movements which they witness in adults. On the other hand, imitative actions may be voluntarily performed as the result of *a desire* to execute them, which involves a distinct idea of the object; and the moving force of this desire is derived from the pleasure which the individual derives from the performance, and which he finds either in the act itself, or in the enjoyment which it affords to others, or in its prospective benefits to himself. Thus we see that the Mind (properly so called) is concerned in all Emotional actions; whilst there is no evidence of the participation of any higher attribute than sensation in the purely Instinctive acts; and even this is not a requisite link in the chain by which many of those movements are excited, that are usually grouped together under that designation.

919. Again, the Emotions may be excited by operations of the Mind itself, as well as by sensations immediately received from without. Thus, involuntary laughter may result from a ludicrous idea, called-up by some train of association, and having no obvious connection with the sensation which first set this process in operation; and the various movements of the face and person by which Actors endeavour to express strong emotions, are most effectual in conveying their meaning, when they result from the actual working of the emotions in the mind of the performer, who has, by a voluntary effort, identified himself (so to speak) with the character he personates. A still more remarkable case is that in which paroxysms of Hysterical convulsion, in themselves beyond the power of the Will to excite or to control, are brought-on by a voluntary effort; this being exerted, not in the attempt to perform the movements, but in 'getting-up' (so to speak) the state of feeling, from which, when it is once excited, the movements spontaneously flow. In all these instances, and others of like nature, it would seem as if the agency of the Cerebrum produced the same condition in the Automatic centres, as that which is more directly excited by sensa-

tions received through their own afferent nerves.—But on the other hand, the Emotions, by their influence on the Reasoning processes, are largely concerned in many actions which are strictly voluntary. In fact, it may be questioned whether there are *any* of our actions, the *power* necessary for whose performance is not derived, directly or indirectly, from emotional states of mind; for our *motives* to any kind of exertion are found, if carefully analysed, to consist in great part in the anticipation of pleasure to be derived or pain to be avoided, either in the performance of the action, or in the consequences which our reasoning processes connect with it. And it will be found that the difference between those persons who are said to act from *feeling*, and those who are said to be guided by *reason*, is not precisely what these terms imply; for the actions of both are equally determined by the motives supplied by emotional states; and the difference rather lies in this, that one class act on their *first* impulses without considering the consequences, whilst the other calculate the *remoter* results, and weigh the future pain against the present pleasure, the ultimate enjoyment against the immediate distress.—The Emotional states are peculiarly liable to be influenced by the condition of the corporeal system; thus a very slight depravation of the blood may produce an irresistible tendency to take a gloomy view of everything to which the mind may be directed, and especially of all that relates to the individual; whilst that condition of perfect health which is derived from wholesome recreation, fresh air, active exercise, &c., is almost always accompanied with a degree of cheerfulness and elasticity, which occasions even real evils to be but comparatively little felt.

920. When we turn our attention to the *Intelligential* actions, of which the Cerebrum appears (in our present state of being) to be the exclusive instrument, we perceive that the attribute by which they are distinguished both from the Instinctive and Emotional, is their *intentional* or *purposive* performance, in accordance with the mental conception of the object to be attained, and the intellectual belief as to the most advantageous means of accomplishing it.—Now when we come to analyse the faculties concerned in this class of operations, we find that the one most closely related to the simple Sensorial powers already treated-of, and at the same time most essential to all the higher operations, is *Memory*. This faculty is one of those first awakened in the opening mind of the Infant; and we find traces of it in animals that seem to be otherwise guided by pure Instinct. It obviously affords the first step towards the exercise of the reasoning powers, since no *experience* can be gained without it; and the foundation of all intelligent adaptation of means to ends, lies in the application of the knowledge which has been acquired and stored-up in the mind. There is strong reason to believe that this attribute belongs to the Cerebrum exclusively; no impressions made upon the Sensorial centres being ever remem-

bered, unless they are registered (as it were) in this organ. And further, there is evidence that no impression of this kind once made upon the Cerebrum is ever entirely lost in the normal state; although disease or accident will sometimes occasion a complete destruction of the memory, or will obliterate the remembrance of a particular class of objects or of ideas. All memory, however, seems to depend upon the principle of *Suggestion;* one idea being linked with another, or with a particular sensation, in such a manner as to be called-up by its recurrence; and a period of many years frequently intervenes, without that combination of circumstances presenting itself, which is requisite to arouse the dormant impression of some early event. Sometimes this combination occurs in Dreaming, Delirium, or Insanity, three states which agree in this, that the Will has no control over the current of thought; and ideas are thus recalled, of which the mind in a state of healthy activity, has no remembrance.—It is upon the ideas aroused in the mind by Sensorial changes, or recalled by *Conception*, or evolved by the process of *Reflection* (in which the mind perceives its own operations, and traces relations amongst its objects of thought), or generated by the *Imagination* (which really acts, however, rather by making new combinations, than by creating altogether *de novo*), that all acts of *Reasoning* are based. These consist, for the most part, in the aggregation and collocation of ideas, the decomposition of complex ideas into more simple ones, and the combination of simple ideas into general expressions: in which are exercised the faculty of *Comparison*, by which the relations and connections of ideas are perceived; that of *Abstraction*, by which we fix our attention on any particular qualities of the object of our thought, and isolate it from the rest; and that of *Generalization*, by which we form some definite apprehensions in regard to the general relations of those objects. These are the processes chiefly concerned in the simple acquirement of Knowledge, with which class of operations the Emotional part of our nature has very little participation, save as furnishing the *desire* which may be the necessary incitement in the exertion of the intellect. But in the direction of our conduct in life, as just now shown, the Emotions have the principal share; since they afford some of the principal motives, either immediate or remote, by which our decisions are guided. In proportion, however, as the Moral Sense, or the estimate of an action according to the standard of *right* and *wrong*, has been developed, and as its dictates are habitually attended-to, will it acquire a predominance over other motives, and become the guiding principle in every contingency in which it can properly be brought to bear.

921. Now the Mind, when not engrossed in taking cognizance of outward objects, is incessantly occupied in *thinking*, with or without the accompaniment of *feeling;* its whole inner life being *a succession of Ideas and Emotions*, only suspended by Sleep and Death.

A certain measure of mental activity seems natural to Man, provided that the development of his powers has taken-place under favourable circumstances; and some of his highest pleasures are derived from the healthful and almost spontaneous exercise of its faculties. Now there is no doubt in the mind of any intelligent Psychologist, that the succession of mental states is essentially dependent on two sets of conditions;—namely, first, the succession of external impressions fitted to excite various kinds of mental action; and, second, the mental constitution of the individual. This mental constitution depends in great degree upon the original condition of the bodily organism, and upon the circumstances in which the individual has been placed; which influences concur to establish certain *tendencies to thought and feeling*, which manifest themselves alike in the ordinary course of conduct, and in the more express products of the mental labour of the individual. Now in so far as the succession of our thoughts takes-place in accordance with the *habitudes* which are thus determined, may we consider that our character is formed *for* us, rather than *by* us; and we may look upon our Mental activity, whether it manifest itself in the form of Thought or of Feeling, as no less *automatic* than the instinctive operations of the lower animals, though far more elevated in its nature. There can be no reasonable doubt that a large proportion of our ordinary Mental life is of this character; the current of thought often flowing-on continuously without any interference on the part of the Will, just as our limbs continue to execute their habitual succession of movements in the act of walking, when the volitional direction is completely drawn-off from them. Many muscular actions too, are the expression of the ideas which have for a time possession of the mind, as we most characteristically see in the states of Reverie, Somnambulism, Electro-Biology, &c., in which the Will is in temporary abeyance; such movements may be appropriately designated *Ideo-motor*, and may be considered as the expressions of a reflex action of the Cerebrum.

922. But the Will possesses a certain determining power over the mental as over the bodily operations; and it is, in fact, this determining power, which is the source of the *self-control* that characterizes the well-regulated mind of Man, and distinguishes him alike from the madman and the brute, giving him to a certain extent the power of forming his character *for himself*. The regulation of our conduct consists in the application of our reasoning powers to the circumstances of our condition, and in the due regulation of those emotional tendencies, which are the moving springs of our actions. However powerful these tendencies may be, there can be no doubt that we possess within ourselves the means of checking them, by withdrawing our minds by a voluntary effort from the thoughts which they suggest, as well as by calling-forth opposing influences, within us; so that the decision which is finally arrived-at may be

something very different from that which the first 'balance of motives' would have produced. It is the deficiency or entire loss of this power of self-control, which usually constitutes the first step in the development of Insanity; for this state generally consists, not so much in a perversion of the reasoning processes, as in a disorder of the emotional state, which causes the patient to dwell upon particular trains of thought, until his feelings in relation to them become exaggerated or perverted; and at last intellectual delusions arise, from the habit of viewing everything that comes before the mind through a distorted medium, and from the substitution of the patient's morbid imaginings for real occurrences. In the purely *impulsive* form of Insanity, there is no intellectual perversion; but a desire of some kind is so powerfully excited, that the Will cannot control it. And every phase may be witnessed, between a state of this kind which renders the individual an irresponsible agent, and that mental condition in which the individual, though originally fully able to control himself, habitually gives way to his passions, and thus, by their continual indulgence, at last allows them to become the dominant powers of his mind.

923. Although the Will has been commonly regarded as *directly determining* those muscular movements which are usually distinguished as Voluntary, through the intermediation of fibres originating in the Cerebral convolutions and proceeding to the muscles, yet a careful analysis of the process fully bears-out the idea already put forwards, that the Will really operates through the Automatic apparatus, exciting particular groups of muscular actions, just as they would be called-forth by sensations directly excited by external objects. For it has been shown that the *Cranio-spinal Axis* (consisting of the Sensory Ganglia, Medulla Oblongata, and Spinal Cord) receives all the sensory nerves, and gives origin to all the motor; and that the fibres which pass between the Cerebral convolutions and the Sensory Ganglia, probably serve to bring these centres into mutual relation, and are not continuous with those of any nerves, either sensory or motor (§ 914). And we might expect, therefore, that the addition of a Cerebrum to this automatic apparatus would have the effect of supplying a new stimulus to movement, which, whilst proceeding from mental operations, should still act through the same mechanism as that already provided for the Spinal and Consensual movements. Now when we attentively consider the nature of what we are accustomed to call *voluntary* action, we perceive that the agency of the Will is limited to the determination of the result; and that it has nothing to do with the selection and co-ordination of the individual movements by which that result is brought-about. If it were otherwise, we should be dependent upon our anatomical knowledge for our power of performing even the simplest movements of the body. Again, there are very few cases in which we can single-out any individual muscle,

and put it into action independently of others; and the cases in which we *can* do so, are those in which a single muscle is concerned in producing the result, as in the elevation of the eyelid; and we then really single-out the muscle by 'willing' the result. Thus, then, however startling the position may at first appear, we have a right to affirm that the Will cannot exert any direct or immediate power over the muscles; but that its determinations are carried into effect through an intermediate mechanism, which, without any further guidance on our own part, selects and combines the particular muscles whose contractions are requisite to produce the desired movement. We have seen that the Sensorial centres play (so to speak) upon the Cerebrum, sending to it impressions of a kind fitted to call-forth its peculiar activity as an instrument of purely mental operations; and in return, the Cerebrum appears to play downwards upon the motor portion of the automatic apparatus, sending to it volitional impulses which excite its motorial activity. And thus we see that the very same action may be excited by an impression conveyed to the centres of the whole system through some one or more nerves of the *external senses*, or through the fibres converging to them from the cerebral convolutions, which have been not unaptly called 'the nerves of the *internal senses*:' and may hence be *automatic* in the first case, and *volitional* in the second. For example, in the act of Coughing, we have the very same combination and succession of diverse but mutually-related actions, whether the operation be excited by the presence of an irritating particle in the air-passages, or be performed as the consequence of a voluntary effort. And a little attention to his own consciousness will satisfy the reader, that, as regards the selection and co-ordination of the movements which are called-forth, the Intelligence and Will are no more concerned in the one case than in the other.—And hence it follows, that all the movements which are performed by the instrumentality of the Cerebro-Spinal system of ganglia and nerves, are in their essential nature automatic; and that their character as Reflex, Instinctive, Emotional, or Voluntary, is entirely dependent on the nature and seat of the impulses which respectively originate them.

924. There are various conditions, some of them natural, others morbid, in which the distinctness of the functions of the Cerebral Hemispheres is well marked. Thus in profound Sleep, they seem to be entirely dormant; the Spinal Cord and Medulla Oblongata, by which the necessary *reflex* actions are carried-on, being alone in a state of activity. In this condition, the Sensory ganglia also appear to be in a torpid state; but in less profound sleep, actions are often performed, which may be referred to the *consensual* group,—being such as the sensation would immediately prompt without any reflection, and not being remembered in the waking state. Thus we turn in our beds under the influence of an uneasy

sensation; or we give some sign of recognition when our names are called. The first of these appears to be a purely consensual movement, being as *automatic* as if it were a reflex action; the other seems to have *become* as automatic, by the influence of habit, and to belong to that class of *secondarily-automatic* actions, in which the movement, though at first directed by the will, has become, after very frequent performance, so closely associated with the guiding suggestion, as to be called-forth by it alone (§ 904).—In the Coma of apoplexy, narcotic poisoning, &c., we witness the same gradations as in ordinary sleep. When it is least profound, it seems to affect the Cerebral hemispheres alone; the Sensory Ganglia being still, in some degree, open to the reception of impressions. When complete, however, none but reflex actions can be excited; and if it advance to a fatal termination, it does so by the supervention of the same state of torpidity in the Medulla Oblongata, whereby the respiratory movements are brought to a close. These movements do not cease until the power of deglutition has been lost, and until the eye ceases to close when the edge of the lid is irritated; but when this is the case, a fatal termination may be apprehended, as it is thus shown that the torpor is extending to the Spinal system of nerves.—In the condition of Dreaming, it would seem as if the Cerebrum were *partially* active; a train of thought being suggested, frequently by sensations from without, which is carried-on without any controlling or directing power on the part of the Mind; and which is not corrected, or is only modified in a limited degree, by the knowledge acquired by experience. This condition is still more remarkable in Somnambulism, or (as it has been better termed) Sleep-waking; in which the dreams are not only *acted*, but may be often *acted-on* with the utmost facility,—a suggestion conveyed through any of the senses excepting sight (which is usually in abeyance) being apprehended and followed-up with the utmost readiness, and, in like manner, with little or no correction from experience. Between this condition, and that of ordinary dreaming, on the one hand, and that of complete insensibility on the other, there is every shade of variety; which is presented by different individuals, or by the same individual at different times. The Cerebellum, in the Sleep-waking state, seems to be frequently in a condition of peculiar activity; a remarkable power of balancing and combining the movements of the body, being often exhibited.

925. On the other hand, there may be an undue exaltation or a perversion of Mental activity, without any affection of the sensorial apparatus. This is well seen, for example, in the first stage of Alcoholic excitement, and in that of Mania, Phrenitis, and other disorders in which the Cerebral Hemispheres are especially affected. Frequently, as in the case of Alcohol, Opium, Haschish, &c., we may directly attribute the morbid action of the Cerebrum to the presence of a poison in the blood which permeates it; and there is

strong reason to believe that many other forms of Delirium are partly due to a perverted state of that fluid. On the other hand, there can be no doubt that an extreme depression of intellectual power, as well as of the emotional state, is often to be attributed to a depravation of the blood; a slight accumulation of bile being very prone to occasion this state in some individuals, and an entire change being effected by a mild dose of a mercurial preparation, which, by eliminating the bile, restores the circulating fluid to its proper purity. And it may be fairly suspected, that the foul atmosphere in the midst of which a large class of our population habitually lives, has the effect, by keeping their blood charged with noxious matters, of so perverting the actions of the brain, that neither the intellectual powers nor the moral sense can be duly exercised; and thus it may be anticipated that Sanitary Reform will largely benefit not merely the corporeal but the mental and moral health of those, whose position is at present one of fearful degradation from the want of it.

8. *Functions of the Sympathetic System.*

926. The Cerebro-Spinal apparatus, of which the several parts have now been described, is not the only system of ganglia and nerve-trunks that is contained within the body of a Vertebrated animal. There is another system, having its own set of centres, and its own distribution of branches, characterized also by a peculiarity in the nature of the nervous fibres of which its trunks are composed, and connected at numerous points with the preceding. It will be remembered that, in front of the vertebral column, there is a series of ganglia on each side; communicating, on the one hand, with the spinal nerves, as they issue from the vertebral canal; and also connecting themselves with the two large Semilunar ganglia which lie amidst the abdominal viscera, as well as with a series of ganglia that is found near the base of the heart. In the head, also, there are numerous scattered ganglia which evidently belong to the same system; having several communications with the cephalic nerves, and being also connected with the chain of ganglia in the neck. The branches proceeding from this series of ganglia are distributed, not to the skin and muscles (like those of the cerebro-spinal system), but to the organs of digestion and secretion, to the heart and lungs, and particularly to the walls of the blood-vessels, on which they form a plexus whose branches probably accompany their minutest ramifications. The peculiar connection of this system of nerves with the organs of vegetative life, has caused it to receive the designation of the 'nervous system of organic life;' the Cerebro-Spinal system being termed the 'nervous system of animal life.' It is also not unfrequently termed the *ganglionic* system; on account of the separation of its centres into scattered ganglia, which forms

a striking contrast to the concentration that is so evident in the Cerebro-Spinal system. But this term is objectionable, as leading to a supposed analogy between this system and the general nervous system of Invertebrata, whose centres are equally scattered;—an analogy which is completely erroneous, since, as we have seen, this last is chiefly the representative of the Cerebro-Spinal system of Vertebrated animals. The term *Sympathetic* is perhaps the best; although it must not be supposed that this system of nerves is the instrument of by any means *all* the sympathies, which manifest themselves between different organs.

927. The Sympathetic system contains both classes of nervous fibres;—the ordinary white tubular fibres, all of which are probably derived from the Cerebro-Spinal system; and the *grey* or *gelatinous* fibres, part of which seem to belong to itself (§ 375). Thus we may consider each system as intermingling itself with the other;—the Cerebro-Spinal system transmitting some of its fibres, both motor and sensory, into the Sympathetic;—whilst the Sympathetic is represented in the Cerebro-Spinal system, by certain fibres and collections of vesicular matter of its own. The trunks that proceed from the Semilunar ganglia, are almost entirely composed of grey or organic fibres; whence it is evident that these ganglia are to be regarded as the true centres of the Sympathetic system. On the other hand, the trunks which issue from the chain of spinal ganglia, contain a large admixture of white or tubular fibres.

928. The nerves of the Sympathetic system possess a certain degree of power of exciting Muscular contractions in the various parts to which they are distributed. Thus by irritating them immediately after the death of an animal, contractions may be excited in any part of the alimentary canal, from the pharynx to the rectum, according to the trunks which are irritated,—in the heart, after its ordinary movements have ceased,—in the aorta, vena cava, and thoracic duct,—in the ductus choledochus, uterus, fallopian tubes, vas deferens, and vesiculæ seminales. But the very same contractions may be excited, by irritating the roots of those Spinal nerves from which the Sympathetic trunks receive their white fibres; and there is, consequently, strong reason to believe, that the *motor* power of the latter is entirely dependent upon the Cerebro-spinal system. Whatever *sensory* endowments the Sympathetic trunks possess, are probably to be referred to the same connection. In the ordinary condition of the body, these are not manifested; for the parts exclusively supplied by Sympathetic trunks do not appear to be in the least degree sensible, and no sign of pain is given when the Sympathetic trunks themselves are irritated. But in certain diseased conditions of those organs, violent pains are felt in them; and these pains can only be produced, through the medium of fibres communicating with the sensorium through the spinal nerves.

929. It is difficult to speak with any precision, as to the functions of the Sympathetic system. There is much reason to believe, however, that it constitutes the channel through which the passions and emotions of the mind affect the Organic functions; and this especially through its power of regulating the calibre of the arteries, of which there is now ample evidence from experiment. We have examples of the influence of these states upon the Circulation, in the palpitation of the heart, which is produced by an agitated state of feeling; in the Syncope, or suspension of the heart's action, which sometimes comes-on from a sudden shock; in the acts of blushing and turning-pale, which consist in the dilatation or contraction of the small arteries; in the sudden increase of the salivary, lachrymal, and mammary secretions, under the influence of particular states of mind, which increase is probably due to the temporary dilatation of the arteries that supply the glands, as in the act of blushing; and in many other phenomena. It is probable that the Sympathetic system not only thus brings the Organic functions into relation with the Animal: but that it also tends to harmonize the former with each other, so as to bring the various acts of secretion, nutrition, &c., into mutual conformity. For whilst the *quantity* of a secreted product, or the amount of tissue generated in a part, may be affected by an increase or diminution in the calibre of the vessels supplying it, the *quality* of the secretion, or the character of the tissue, may be likewise affected (there seems valid reason to believe) by that Nervous force, whose relations to the Physical and Chemical, as well as to all other vital forces, are so intimate (§§ 59, 396). And it does not seem improbable that some such regulation of the purely-organic processes, is the function of the *true* Sympathetic system, as distinguished from the part derived from the Cerebro-spinal. Upon this point, however, we have no certain information; and whatever influence the Sympathetic (of which some of the fibres seem to pass into the Cerebro-spinal system) may have upon the acts of Nutrition and Secretion, it is quite certain that these acts may go-on without it. The influence of the Nervous System upon the Organic functions, may, indeed, be compared to the direction and control which a horse receives from his rider, or a locomotive engine from its driver.

CHAPTER XIII.

OF SENSATION, GENERAL AND SPECIAL.

1. *Of Sensation in general.*

930. ALL save the lowest kinds of Animals, possess (there is good reason to believe) a *consciousness* of their own existence, first excited by the corporeal changes taking-place within themselves, and also a greater or less amount of *sensibility* to the condition of external things. This consciousness of what is taking-place within and around the individual, is all derived from *impressions* made upon its afferent nervous fibres; which, being conveyed by them to the central *sensorium*, are there *felt* (§ 390). Of the mode in which the impression, hitherto a change of a physical character, is there made to act upon the *mind*, we are absolutely ignorant; we only know the fact. Although we commonly refer our various sensations to the peripheral parts,—as, for instance, when we say that we have a pain in the hand, or an ache in the leg,—we really use incorrect language; for, though we instinctively refer our sensations to the parts where the impression is first made on the nerves, they are really *felt* in the brain. This is evident from two facts;—first, that if the nervous communication between the part and the brain, be interrupted, no impressions, however violent, can make themselves felt; and second, that if the *trunk* of the nerve be irritated or pinched anywhere in its course, the pain which is felt is referred, not to the point injured, but to the surface on which these nerves are distributed. Hence the well-known fact, that for some time after the amputation of a limb, the patient feels pains which he refers to the fingers or toes that have been removed; and these continue, until the irritation of the cut extremities of the nervous trunks has subsided.

931. It would seem probable that among the lower tribes of Animals, there exists no other kind of sensibility than that termed *general* or *common;* which pervades, in a greater or less degree, nearly every part of the bodies of the higher. It is by this, that we feel those impressions, made upon our bodies by the objects around us, which produce the various modifications of *pain*, the sense of contact or resistance, the sense of variations of temperature, and others of a similar character. From what was formerly stated (§ 403) of the dependence of the *impressibility* of the sensory nerves, upon the activity of the circulation in the neighbourhood of

their extremities, it is obvious that no parts destitute of blood-vessels can receive such impressions, or (in common language) can possess sensibility. Accordingly we find that the hair, nails, teeth, cartilages, and other parts that are altogether extra-vascular, are themselves destitute of sensibility; although certain parts connected with them, such as the bulb of the hair, or the vascular membrane lining the pulp-cavity of the tooth, may be acutely sensitive. Again, in tendons, ligaments, fibro-cartilages, bones, &c., whose substance contains very few vessels, there is but a very low amount of sensibility. On the other hand, the skin and other parts, which are peculiarly adapted to receive such impressions, are extremely vascular; and it is interesting to observe, that some of the tissues just mentioned become acutely sensible, when new vessels form in them in consequence of diseased action. It does not necessarily follow, however, that parts should be sensible in a degree proportional to the amount of blood they may contain; for this blood may be sent to them for other purposes, and they may contain but a small number of sensory nerves. Thus, although it is a condition necessary to the action of Muscles, that they should be copiously supplied with blood (§ 340), they are by no means acutely sensible; and, in like manner, Glands, which receive a large amount of blood for their peculiar purposes, are far from possessing a high degree of sensibility.

932. But besides the *general* or *common* sensibility, which is diffused over the greater part of the body in most animals, there are certain parts which are endowed with the property of receiving impressions of a peculiar or special kind, such as sounds or odours, that would have no influence on the rest; and the sensations which these excite, being of a kind very different from those already mentioned, arouse ideas in our minds such as we should never have gained without them. Thus, although we can acquire a knowledge of the shape and position of objects by the touch, we could form no notion of their colour without sight, of their sounds without hearing, or of their odours without smell. The nerves which convey these *special* impressions, as already mentioned, are not able to receive those of a *common* kind; thus the eye, however well fitted for seeing, would not feel the touch of the finger, if it were not supplied by branches from the Fifth pair, as well as by the Optic; and when either the Olfactive, Optic, or Auditory nerves are pinched, torn, or cut, no indications of pain are given by the animal. Nor can the different nerves of special sensation be affected by impressions that are adapted to operate on others; thus the ear cannot distinguish the slightest difference between a luminous and a dark object; nor could the eye distinguish a sounding body from a silent one, except when the vibrations can be *seen*. But Electricity possesses the remarkable power, when transmitted along the several nerves of special sense, of exciting the sensations peculiar

to each; and thus, by proper management, this single agent may be made to produce flashes of light, distinct sounds, a phosphoric odour, a peculiar taste, and a pricking feeling, in the same individual, at one time. The feeling of *pain* may be induced by the peculiar impressions made through their appropriate organs upon the nerves of special sense, as well as upon those of feeling; if these impressions be too violent or excessive. Thus the dazzling of the eye by a strong light, and still more, the action of a moderate light in an irritable state of the retina,—sudden loud sounds, or even sounds of moderate intensity but of peculiar harshness,—powerful odours, even such as are agreeable in moderation,—produce feelings of uneasiness which may be properly called painful, even though they are different from those excited through the nerves of common sensation.

933. As a general rule, it may be stated that the *violent* excitement of *any* sensation is disagreeable; even when the same sensation, experienced in a moderate degree, may be a source of extreme pleasure. But the question of degree is *relative* rather than *absolute;* that is, a sensation may be felt as extremely violent by one individual; whilst another, who is more accustomed to sensations of the same kind, is not disagreeably affected by it. Thus, our sensations of heat and cold are entirely governed by the previous condition of the parts affected; as is shown by the well-known experiment of putting one hand in hot water, the other in cold, and then transferring them both to tepid water,—which will seem cool to the one hand, and warm to the other. The same is the case in regard to light and sound, smell and taste. A person going out of a totally dark room into one moderately bright, is for the time painfully impressed by the light, but soon becomes habituated to it; whilst another who enters it from a room brilliantly illuminated, will consider it dark and gloomy.

934. The intensity with which sensations are felt, therefore, depends upon the degree of *change* which they produce in the sensorium. The more frequent the recurrence of any particular sensation, the more does the system become adapted to it, and the less change does it produce. It is, therefore, perceived in a less and less degree, and at last it ceases to excite attention. The *stoppage* of a constantly-recurring sensation, however, will produce a change, which makes as strong an impression on the system as its first commencement; thus there are persons who have become so habituated to the sound of a waterfall or even of a forge-hammer, that they cannot sleep anywhere but in its vicinity; and it is well known that, when a person has gone to sleep under the influence of some continuous or frequently-recurring sound (such as the voice of a reader, the dropping of water, the tread of a sentinel, &c.), the cessation of the sound will cause his awaking.

935. The acuteness of particular sensations is influenced in a

remarkable degree by the *attention* they receive from the mind. If the mind be entirely inactive, as in profound sleep, no sensation whatever is produced by very feeble impressions; on the other hand, when the mind is from any cause strongly directed upon them, impressions very feeble in themselves produce sensations of even painful acuteness. It is in this manner, that the habit of attending to sensations of any particular class increases their vividness; so that they are at once perceived by an individual on the watch for them, when they do not excite the observation of others. We may even, by a strong effort, direct the mind into one particular channel, so as to receive only those sensations which have reference to it, and to be unconscious *quoad* all others. Thus, the application of the mind to some particular train of thought may prevent our being conscious of anything that is going-on around or within us,—the conversation of friends,—the striking of the clock,—the calls of hunger, &c. This *abstraction* may be altogether voluntary; and the possession of the power of thus withdrawing the mind at will from the influence of external disturbing causes, and of fixing it upon any particular train of ideas, is an extremely valuable one. But it may also be involuntary, and may be a source of inconvenience from its tendency to recur at improper times,—producing the habitual state which is known as *absence of mind* or *reverie*.

936. It is desirable that we should make a distinction between the *sensations* themselves, and the *ideas* which are the immediate results of those sensations when they are perceived by the mind. These ideas relate to the *cause* of the sensations, or the object by which the impression is made. Thus the formation of the picture of an object upon the retina, produces a certain impression upon the optic nerve; which, being conveyed to the sensorium, excites a corresponding sensation, with which, in all ordinary cases, we immediately connect an idea of the nature of the object. So closely, indeed, is this idea usually related to the sensation, that we are not in the habit of making a distinction between them. Thus I may say at this moment, "I see a book on the table before me;" the fact being, that I am conscious of a certain picture, which conveys to my mind the ideas of a book and of a table, and of their relative positions; these ideas being (in Man) the result of experience and association,—in fact, originating in the immediate application of the knowledge we have previously acquired, that a certain object whose picture we see, is a book, another object a table, and so on. We are liable to be deceived in this assumption; as when, by a clever imitation, a picture on a plane surface is made to represent an object in relief, so perfectly as at once to excite the idea of the latter,—which may not be corrected until we have ascertained by the touch the flatness of the real object.

937. This production of ideas by the agency of sensations, is a process essentially mental, and dependent upon the laws of Mind.

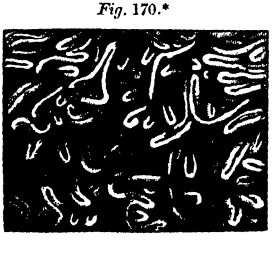
We find that some of these *perceptions* or elementary notions are *intuitive:* that is, they are prior to all experience, and are as *necessarily* connected with the sensation which produces them, as reflex movements are with the impression that excites them. This seems to be the case, for example, with regard to *erect vision.* There is no reason whatever to think, that either infants or any of the lower animals see objects in an inverted position, until they have corrected their notion by the touch; for there is no reason why the inverted picture on the retina should give rise to the idea of the inversion of the object. The picture is so received by the mind, as to convey to us an idea of the position of external objects, which harmonizes with the ideas we derive through the touch; and whilst we are in such complete ignorance of the manner in which the mind becomes conscious of the sensation at all, we need not feel any difficulty about the mode in which this conformity is effected. But in Man, as already stated, the attaching definite ideas to certain groups of lines, colours, &c., with respect to the objects they represent, is a subsequent process, in which experience and memory are essentially concerned; as we see particularly well in cases presently to be referred-to, in which the sense of sight has been acquired comparatively late in life, and in which the mode of using it, and of connecting the sensations received through it with those received through the touch, has had to be learned by a long-continued training. The elementary notions thus formed,—which may, by long habit, present themselves as immediately and unquestionably as if they were intuitive,—are termed *acquired* perceptions.

938. It is probable that, among the lower animals, the proportion of intuitive perceptions is much greater than in Man; whilst, on the other hand, their power of acquiring perceptions is much less than his. Hence, whilst the young of the lower animals very soon becomes possessed of all the knowledge which is necessary for the acquirement of its food, the construction of its habitation, &c., its range is very limited, and it is incapable of attaching any ideas to a great variety of objects of which the Human mind takes cognizance. This correspondence between the acquired perceptions of Man, and the intuitive perceptions of many of the lower animals, is strikingly evident in regard to the power of measuring distance. This is acquired very gradually in the Human infant, or by a person who has first obtained the faculty of sight later in life; but it is obviously possessed by many of the lower animals to whose maintenance it is essential, immediately upon their entrance into the world. Thus a Fly-catcher, immediately after its exit from the egg, has been known to peck-at and capture an insect,—an action which requires a very exact appreciation of distance, as well as a power of precisely regulating the muscular movements in accordance with it.

2. *Of the Sense of Touch.*

939. By the sense of Touch is usually understood that modification of the common sensibility of the body, of which the surface of the Skin is the especial seat, but which exists also in some of its internal reflexions. In some animals, as in Man, nearly the whole exterior of the body is endowed with it in no inconsiderable degree; whilst in others, as the greater number of Mammalia, most Birds, Reptiles, and Fishes, and a large proportion of the Invertebrata, the greater part of the body is so covered with hairs, scales, bony or horny plates, shells of various kinds, complete horny envelopes, &c., as to be nearly insensible; and the faculty is restricted to particular portions of the surface, or to organs projecting from it, which often possess a peculiarly high degree of this endowment. Even in Man, the acuteness of the sensibility of the cutaneous surface varies greatly in different parts; being greatest at the extremities of the fingers and in the lips, and least in the skin of the trunk, arm, and thigh. Thus the two points of a pair of compasses (rendered blunt by bits of cork) can be separately distinguished by the point of the middle finger, when approximated so closely as 1-3rd of a line; whilst they require to be opened so widely as 30 lines from each other, to be separately distinguished, when pressed upon the skin over the spine, or upon that of the middle of the arm or thigh.—The impressions that produce the sense of Touch are most distinct when received through the sensory *papillæ*, with which the surface of the true Skin is beset more or less closely, according to the part of it that is examined. These papillæ are minute elevations, which have been commonly stated to enclose loops of capillary vessels (Fig. 170) and branches of the sensory nerves. The recent observations of Wagner, Kölliker, and others, however, render it probable that the papillæ are essentially of two kinds; namely, the *vascular* (Fig. 141, *p*), which are especially destined to afford nutrition to the epidermis, and which are extraordinarily developed in the matrices of nails, hoofs, &c.; and the *nervous* papillæ (*t*), which are purely sensory. Whether the latter uniformly contain blood-vessels, or, as a rule, are destitute of them, must be considered as still

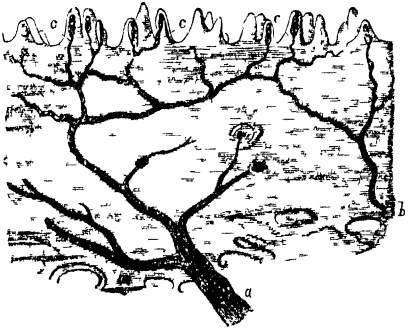
Fig. 170.*



* Capillary network at margin of lips.

doubtful; it is certain, however, that their supply of blood is much inferior to that of the vascular papillæ. The cutaneous nerves form a plexus (Fig 171), from which fibres proceed to the sensory papillæ (*c*, *c*, *c*), and each of these fibres seems to terminate (in

Fig. 171 *



those parts, at least, which are distinguished by acuteness of tactile sensibility) in a peculiar 'axile body, which occupies the principal part of the interior of the papilla, and which may be considered as formed by an increased development of the fibrous tissue that forms the neurilemma of the nerve tubes These 'axile' bodies, not being constantly present in the sensory papillæ, cannot be considered as essential to the exercise of the sense of touch, and their function seems rather to intensify tactile impressions, where delicacy of touch may be peculiarly required

940 It is peculiar to the senses of Touch and of Taste (the latter being in this respect closely allied to the former), that the impression must be made by the *contact* of the object itself with the sensory surface, and not through any intermediate agency The only exception to this is in regard to the sense of *Temperature*, which seems to be in many respects different from ordinary touch here the *proximity* of the warm or cold body is sufficient, the impressions being made after the manner of those of odours, sounds, &c., and no mechanical irritation of the nerves of common sensation ever seems to excite sensations of heat or cold.

* Vertical Section of the *Skin* of the palmar surface of the fore-finger (treated with a solution of caustic soda), showing the branches of cutaneous nerves, *a*, *b*, inosculating to form a terminal plexus, of which the ultimate ramifications pass into the cutaneous papillæ, *c*, *c*, *c*

941. For the exercise of the sense of Temperature, the integrity of the sensory apparatus contained in the Skin appears to be requisite; for it has been ascertained by the recent experiments of Prof. Weber, that if the integuments be removed, the application of hot or cold bodies only causes *pain*, their elevation or depression of temperature not being perceived; and the same is the case, when hot or cold bodies are applied to the nerve-trunks. It is worthy of note that there are many cases on record, in which the sense of Temperature has been lost, while the ordinary Tactile sense remained; and the former is sometimes preserved, when there is a complete loss of every other kind of sensibility. So again we find that the *subjective* sensations of temperature (that is, sensations which originate from changes in the body itself, not from external impressions) are frequently excited quite independently of the tactile sensations; a person being sensible of heat or of chilliness in some part of his body, without any real alteration of its temperature, and without any corresponding affection of the tactile sensations.—It is curious that the intensity of the sensation of temperature should depend, not merely upon the relative degree of heat to which the part is exposed (§ 933), but also upon the extent of the surface over which it is applied; a weaker impression made on a larger surface, seeming more powerful than a stronger impression made on a small surface. Thus, if the forefinger of one hand be immersed in water at 104°, and the whole of the other hand be plunged in water at 102°, the cooler water will be thought the warmer; whence the well-known fact, that water in which a finger can be held without discomfort, will produce a scalding sensation when the entire hand is immersed in it.

942. The only idea communicated to our minds when the sense of Touch is exercised in its simplest form, is that of *resistance;* and we cannot acquire a notion of the size or shape of an object, or of the nature of its surface, through this sense alone, unless we *move* the object over our own sensory organ, or pass the latter over the former. By the various degrees of resistance which we then encounter, we form our estimate of the hardness or softness of the body. By the impressions made upon our sensory papillæ, when they are moving over its surface, we form our idea of its smoothness or roughness. But it is through the *muscular* sense, which renders us cognizant of the relative position of the fingers, the amount of movement the hand has performed in passing over the object, and other impressions of like nature, that we acquire our notions of its size and figure; and hence we perceive that the sense of touch, without the power of giving motion to the tactile organ, would have been of comparatively little use. It is chiefly in the *variety* of movements of which the hand of Man is capable,—thus conducive as they are, not merely to his prehensile powers, but to the exercise of his sensory endowments,—that it is superior to that of any other animal; and it cannot be doubted, that this affords us

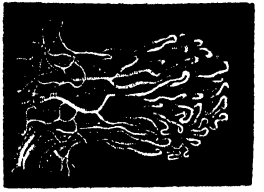
a very important means of acquiring information in regard to the external world, and especially of correcting many vague and fallacious notions which we should derive from the sense of Sight if used alone. On the other hand, it must be evident that our knowledge would have but a very limited range, if this sense were the only medium through which we could acquire ideas. Of this we have the clearest evidence, in the very imperfect development of the mental powers in those unfortunate persons, who have suffered under the deprivation of sight and hearing from their birth, and who have been consequently cut-off from the most direct means of profiting by the knowledge possessed by their fellow-beings, through want of power to use the organs of speech. It is only where such individuals have fallen under the care of judicious and persevering instructors, that their mental powers have been called into their due activity, or that any ideas have been awakened, beyond those immediately connected with the gratification of the animal wants, or with painful or pleasurable sensations. Thus a mind quite capable of being aroused to activity and enjoyment, may remain in a condition nearly allied to that of idiocy, simply for want of the sensations requisite to produce ideas of a higher or more abstract character, than those derived through the senses of Touch, Taste, and Smell.

3. *Of the Sense of Taste.*

943. The sense of Taste, like that of Touch, is excited by the direct contact of particular substances with certain parts of the body: but it is of a nature different from that of touch, inasmuch as it communicates to us a knowledge of properties which that sense would not reveal to us (§ 945). All substances, however, do not make an impression on the organ of Taste. Some have a strong savour, others a slight one, and others are altogether insipid. The cause of these differences is not altogether understood; but it may be remarked that, in general, bodies which cannot be dissolved in water, alcohol, &c., and which thus cannot be presented to the gustative papilla in a state of solution, have no taste. This sense has for its chief purpose to direct animals in their choice of food; hence its organ is always placed at the entrance to the digestive canal. In higher animals, the Tongue is the principal seat of it; but other parts of the mouth are also capable of receiving the impression of certain savours. The mucous membrane which covers the tongue, is copiously supplied with papillæ of various forms and sizes. Those of simplest structure closely resemble the cutaneous papillæ; but there are others which resemble clusters of such papillæ, each being composed of a fasciculus of looped capillaries (Fig. 172), with a bundle of nerve-fibres, whose precise mode of termination it has not yet been found possible to ascertain. These

fungiform papillæ, which are covered with a very thin epithelium, are probably the special instruments of the sense of taste; for the exercise of which it seems probable that the sapid substances must penetrate (in solution) to the interior of the papilla. When these papillæ are called into action by the contact of substances having a strong savour, they not unfrequently become very turgid, by a distension of their vessels analogous to that which occurs in 'erection;' and they rise-up above the level of the mucous membrane, so as to produce a decided roughness of its surface.—The *conical* papillæ, on the other hand, are furnished with thick epithelial investments, which are sometimes prolonged into filamentous appendages; and looking to their higher development among other animals, and the offices to which they are there subservient, it seems probable that *their* functions are purely mechanical, and that they serve especially to cleanse the teeth from adhering particles. The nerve-fibres can be seen to form distinct loops in their interior, at some distance from their apex.

Fig. 172.*



944. There has been much discrepancy of opinion as to the nerve which is specially concerned in the sense of Taste. The tongue of Man is supplied by two sensory nerves; the Lingual branch of the Fifth pair; and the Glosso-pharyngeal. The former chiefly supplies the upper surface of the front of the tongue, and is copiously distributed to the papillæ near the tip. The latter is mostly distributed upon the mucous surface of the fauces, and upon the back of the tongue; but it sends a branch forwards, beneath the lateral margin on each side, which supplies the edges and inferior surface of the tip of the tongue, and inosculates with the preceding. There is reason to believe, from experiment, that the gustative sensibility of the tongue is not destroyed by section of either of these nerves, though the operation produces a total or partial loss of sensibility over certain parts of the surface; and a like inference may be drawn from observation of cases of paralysis. From these and other considerations there seems good reason to conclude, that the Lingual branch of the Fifth pair is the nerve through which the sense of Taste, as well as that of Touch, is exercised, in the parts of the tongue to which it is specially distributed, which are those that possess both senses in the most acute degree; and that the Glosso-pharyngeal is subservient to the same functions in the parts supplied by *it*,—being probably the exclusive channel, also, through

* Capillary network of Fungiform papilla of the Tongue.

which the impressions made by disagreeable substances taken into the mouth, are propagated to the Medulla Oblongata, so as to produce nausea and excite efforts to vomit. The latter nerve is also, as we have seen, the principal channel of the impressions that give rise to the reflex act of swallowing; with which the fifth pair is concerned in a much inferior degree (§ 897).

945. A considerable part of the impression produced by many substances taken into the mouth, is received through the sense of Smell, rather than through that of Taste. Of this any one may easily satisfy himself, by closing the nostrils and breathing through the mouth only, whilst holding in his mouth, or even rubbing between his tongue and his palate, some aromatic substance; its taste is then scarcely recognized, although it is immediately perceived when the nasal passages are re-opened, and its effluvia are drawn into them. There are many substances, however, which have no aromatic or volatile character; and whose taste, though not in the least dependent upon the action of the nose, is nevertheless of a powerful character. Some of these produce, by irritating the mucous membrane, a sense of *pungency*, allied to that which the same substances (mustard, for instance) will produce, when applied to the skin for a sufficient length of time, especially if the Epidermis have been removed. Such sensations, therefore, are evidently of the same *kind* with those of Touch, differing from them only in the *degree* of sensibility of the organ through which they are received. But there are others which produce sensations entirely different from any that can be received through the skin, and which are properly distinguished, therefore, as *gustative;* such are common Salt, which may be considered as a type of the saline taste, Sugar the type of the saccharine, Quinine of the bitter, Tannin of the astringent, and Citric acid of the sour. All such substances, therefore, are said to possess *sapid* properties, exciting distinctive tastes, quite irrespectively of any aromatic or odoriferous properties which they may also possess, as well as of their stimulating action on the skin.

4. *Of the Sense of Smell.*

946. Certain bodies possess the property of exciting sensations of a peculiar nature, which cannot be perceived by the organs of taste or touch, but which seem to depend upon the diffusion of the particles of the substance through the surrounding air, in a state of extreme minuteness. As the solubility of a substance in liquid seems a necessary condition of its exciting the sense of taste, so does its volatility, or tendency to a vaporous state, appear requisite for its having Odorous properties. Most volatile substances are more or less odorous; whilst those which do not readily transform themselves into vapour, usually possess little or no fragrance in the

liquid or solid state, but may acquire strong odorous properties as soon as they are converted into vapour,—by the aid of heat, for example. There are some solid substances, however, which possess very strong odorous properties, without losing weight in any appreciable degree by the diffusion of their particles through the atmosphere. This is the case, for example, with Musk; a grain of which has been kept freely exposed to the air of a room whose door and windows were constantly open, for a period of ten years; during which time the air, thus continually changed, was completely impregnated with the odour of musk; and yet, at the end of that time, the particle was not found to have perceptibly diminished in weight. We can only attribute this result to the extreme minuteness of the division of the odorous particles of this substance. There are other odorous solids, such as Camphor, which rapidly lose weight by the loss of particles from their surface, when freely exposed to the air.

947. The conditions of the sense of Smell are very simple. The Olfactory nerve is minutely distributed over the Schneiderian membrane (Fig. 173), which is itself highly vascular. The arrange-

Fig. 173.*



* The Olfactory nerve, with its distribution on the Septum Nasi: the nares have been divided by a longitudinal section made immediately to the left of the septum, the right nares being preserved entire —1, The frontal sinus; 2, the nasal bone; 3, the crista galli process of the ethmoid bone; 4, the

ment of the ultimate fibres of this nerve has not been ascertained. The Schneiderian membrane is kept constantly but moderately moist, by a mucous secretion from its surface; and this condition is essential to the acute perception of odours. If the mucous surface be too dry, as happens when the fifth pair is paralysed, the sensation is blunted or even destroyed; and the same effect is produced by the presence of too copious a secretion, as when we are suffering under an ordinary 'cold.'—The highest part of the nasal fossæ appears to be that in which there is the most acute sensibility to odours; and hence it is that when we *snuff* the air, so as to direct it into this portion of the cavity, we perceive delicate odours which would otherwise have escaped us. The acuteness of the sense of Smell depends, in no small degree, upon the extent of surface exposed by the membrane lining the nasal cavity; and in this respect Man is far surpassed by many of the lower Mammalia, especially the Ruminants, which are warned by its means of the proximity of their enemies. The habit of *attention* to sensory impressions of this class, however, very much heightens their acuteness; hence in those who suffer under blindness and deafness conjointly, it is usually the principal means by which individuals are distinguished and the presence of strangers recognised; and there are cases in which individuals in a state of Somnambulism (in which there is often an extraordinary concentration of the mind upon some one particular kind of sensory impressions) have exhibited a degree of acuteness of smell quite comparable to that which is characteristic of Deer, Antelopes, &c.

948. Besides ministering to the sense of Smell, by stimulating the secreting powers of its surface, the Fifth pair has another very important function,—that of endowing the interior of the nose with *common* sensibility, and thus receiving the impressions produced by acrid or pungent substances, which act upon it in the same way as they do upon the tongue. Such substances are *felt*, by the irritation they produce, rather than *smelt*; and the sensation they occasion gives-rise to the consensual act of *sneezing*, by which a violent

sphenoidal sinus of the left side; 5, the sella turcica; 6, the basilar process of the sphenoid and occipital bones; 7, the posterior opening of the right nares; 8, the opening of the Eustachian tube in the upper part of the pharynx; 9, the soft palate, divided through its middle; 10, cut surface of the hard palate; *a*, the olfactory peduncle; *b*, its three roots of origin; *c*, olfactory ganglion, from which the filaments proceed that spread-out in the substance of the pituitary membrane; *d*, the nasal nerve, a branch of the ophthalmic nerve descending into the left nares from the anterior foramen of the cribriform plate, and dividing into its external and internal branch; *e*, the naso-palatine nerve, a branch of the spheno-palatine ganglion distributing twigs to the mucous membrane of the septum nasi in its course to (*f*) the anterior palatine foramen, where it forms a small gangliform swelling (Cloquet's ganglion) by its union with its fellow of the opposite side; *g*, branches of the naso-palatine nerve to the palate; *h*, posterior palatine nerves; *i*, *i*, the septum nasi.

blast of air is directed through the nasal passages, in such a manner as to clear them of the irritating matter, whether solid (as snuff), fluid, or gaseous. Hence this action may be excited by the contact of an irritant with the Schneiderian membrane, after the olfactory nerve has been divided, if the branches of the fifth pair be entire; whilst it does not take-place when the fifth pair is paralysed, even though the sense of smell is retained.

5. *Of the Sense of Hearing.*

949. By this sense we become acquainted with the sounds produced by bodies in a certain state of vibration; the vibrations being propagated through the surrounding medium, by the corresponding waves or undulations which they produce in it. Although air is the usual medium through which sound is propagated, yet liquids or solids may answer the same purpose. On the other hand, no sound can be propagated through a perfect vacuum.—It is a fact of much importance, in regard to the action of the Organ of Hearing, that sonorous vibrations which have been excited, and are being transmitted, in a medium of one kind, are not imparted with the same readiness to others. The following conclusions have been drawn from experimental inquiries on this subject.

I. Vibrations excited in solid bodies, may be transmitted to water without much loss of their intensity; although not with the same readiness that they would be communicated to another solid.

II. On the other hand, vibrations excited in water lose something of their intensity in being propagated to solids; but they are returned, as it were, by these solids to the liquid, so that the sound is more loudly heard in the neighbourhood of these bodies, than it would otherwise have been.

III. The sonorous vibrations are much more weakened in the transmission of solids to air; and those of air make but little impression on solids.

IV. Sonorous vibrations in water are transmitted but feebly to air; and those which are taking-place in air are with difficulty communicated to water; but the communication is rendered more easy by the intervention of a membrane extended between them.

The application of these conclusions, in the Physiology of Hearing, will be immediately apparent.

950. It is on the *Auditory* nerve (commonly termed the Portio Mollis of the 7th pair), that the sonorous undulations make their impression; but we invariably find that this impression is made through the medium of a liquid contained in a cavity, on the walls of which the ultimate branches of this nerve are distributed. The simplest form of the organ of Hearing, such as we find in Cephalopods and in certain Fishes, consists merely of a cavity excavated

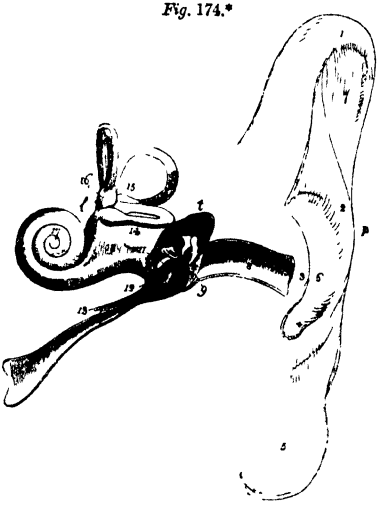
in the solid framework of the head; which cavity is filled with liquid, and lined by a membrane on which the auditory nerve is distributed. These animals are inhabitants of the water; and the sonorous vibrations excited in this medium, being communicated to the solid parts of the head will be by them again transmitted to the contained fluid without much diminution of their intensity, according to principles I. and II.—In certain Crustacea, however, whose organ of hearing is contained in the base of the antennæ, as well as in most Fishes, we find the auditory cavity or vestibule no longer entirely closed; but having an aperture on its external side, which is covered-in by a membrane. Here the vibrations of the liquid within the cavity will be more directly excited by those of the surrounding medium; for if this be water, it will propagate its undulations into the cavity with little interruption from the membrane stretched across its mouth; whilst, if it be air, the interposition of this very membrane will greatly assist in the transmission of the vibrations to the water of the auditory cavity, according to principle IV. In most of the animals which have the organ of hearing constructed on this simple plan, the force of the vibrations of the fluid within the cavity is increased by several minute stony concretions (termed *otolithes*), which are suspended in it. These act according to principle II. Some traces of them are found in the higher animals; in which they are for the most part superseded, however, by an apparatus better adapted to augment the intensity of the sonorous vibrations.

951. This apparatus consists, in all Vertebrated animals above the inferior Reptiles, of the tympanum or drum, with its membrane and chain of bones; together with, in the Mammalia, an external ear, which is adapted to direct itself, more or less completely, towards the point from which the sonorous vibrations proceed, and seems to give them a degree of preliminary concentration. The tympanic apparatus is interposed between the external ear and the membrane covering the *foramen ovale*, which is the entrance to the real auditory cavity; and its purpose is evidently, to receive the sonorous vibrations from the air, and to transmit them to that membrane, in such a manner that the vibrations thus excited in the latter may be much more powerful than they would be if the air acted immediately upon it, as it does in the lower Vertebrata. —The usual condition of the Membrana Tympani appears to be rather lax; and, when in this condition, it vibrates in accordance with grave or deep tones. By the action of the tensor tympani it may be tightened, so as to vibrate in accordance with sharper or higher tones; but it will then be less able to receive the impressions of deeper sounds. This state we may easily induce artificially, by holding the breath, and forcing air from the throat into the Eustachian tube, so as to make the membrane bulge-out by pressure from within; or by exhausting the cavity by an effort at in-

spiration, with the mouth and nostrils closed, which will cause the membrane to be pressed inwards by the external air. In either case the hearing is immediately found to be imperfect; but the deficiency relates only to grave sounds, acute ones being heard even more plainly than before. There is a different limit to the acuteness of the sounds of which the ear can naturally take cognizance in different persons. If the sound be so high in pitch, that the membrana tympani cannot vibrate in unison with it, the individual will not hear it, even though it be loud; and it has been noticed that certain individuals cannot hear the very shrill tones produced by particular Insects or even Birds, which are distinctly audible to others.

952. Not only do we find the tympanic apparatus superadded, in the higher forms of the organ of Hearing, but also the Semicircular Canals (Fig. 174, 15), and the Cochlea (17).—The former

Fig. 174.*



* A diagram of the Ear:—*p*, The pinna; *t*, the tympanum; *l*, the labyrinth; 1, the upper part of the helix; 2, the antihelix; 3, the tragus; 4, the antitragus; 5, the lobulus; 6, the concha; 7, the upper part of the fossa scaphoidea; 8, the meatus; 9, the membrana tympani, divided by the section; 10, the three little bones, malleus, incus, and stapes, crossing the area of the tympanum, the foot of the stapes blocking up the fenestra ovalis upon the inner wall of the tympanum; 11, the promontory; 12, the fenestra rotunda; the dark opening above the ossicula leads into the mastoid cells;

exist in all Vertebrata, save the lowest Fishes; and in nearly every case they are *three* in number, and lie in three different planes. Hence it has been supposed, with some probability, that they assist in producing the idea of the *direction* of sounds. The *Cochlea* does not exist at all in Fishes; and in Reptiles its condition is quite rudimentary. In Birds, this cavity is more completely formed, though the passage is nearly straight instead of spiral; of its real character, however, there can be no doubt, from its being divided, like the cochlea of Man, by a membranous partition, on which the ramifications of the auditory nerve are spread out. This appendage has been supposed to be the organ that enables us to judge of the *pitch* of sounds; an idea which derives some confirmation from the correspondence between the development of the cochlea in different animals, and the variety in the pitch (or length of the scale) of the sounds which it is important that they should hear distinctly, especially the voices of their own kind.—That the Vestibule, with the passages proceeding from it, constitutes the true organ of hearing, even in Man, is evident from the fact, that when (as not unfrequently happens) the tympanic apparatus has been entirely destroyed by disease, so as to reduce the organ to the condition of that in which no such apparatus exists, the faculty of Hearing is by no means abolished, although it is deadened.

953. The faculty of Hearing, like other senses, may be very much increased in acuteness by cultivation; but this improvement depends rather upon the habit of attention to the faintest impressions made upon the organ, than upon any change in the organ itself. This habit may be cultivated in regard to sounds of some particular class; all others being heard as by an ordinary person. Thus, the watchful North American Indian recognises footsteps, and can even distinguish between the tread of friends and foes; whilst his white companion, who has lived among the busy hum of cities, is unconscious of the slightest sound. Yet the latter may be a musician, capable of distinguishing the tones of all the different instruments in a large orchestra, of following any one of them through the part which it performs, and of detecting the least discord in the blended effects of the whole,—effects which would be to the unsophisticated Indian but an indistinct mass of sound. In the same manner, a person who has lived much in the country, is able to distinguish the note of every species of bird that lends its

13, the Eustachian tube; the little canal upon this tube contains the tensor tympani muscle in its passage to the tympanum; 14, the vestibule; 15, the three semicircular canals, horizontal, perpendicular, and oblique; 16, the ampullæ upon the perpendicular and horizontal canals; 17, the cochlea; 18, depression between the convexities of the two tubuli which communicate with the tympanum and vestibule; the one is the scali tympani, terminating at 12; the other is the scala vestibuli.

voice to the general chorus of nature; whilst the inhabitant of a town hears only a confused assemblage of shrill sounds, which may impart to him a disagreeable rather than a pleasurable sensation.

954. In all continued sounds or *tones*, there are several points to be attended-to. In the first place, we take cognizance of their *pitch;* which depends upon the *number* of vibrations in a given time,—the high notes being produced by the most rapid vibrations, and the low notes by the slowest. The ear can appreciate tones produced by 24,000 impulses per second, the pitch of which is about four octaves above the highest F of the piano-forte. On the other hand, no sequence of vibrations fewer than 7 or 8 in a second, can produce a continuous tone, because the impression left by each impulse has passed-away before the next succeeds, so that there is nothing more than a succession of distinct beats.—The *strength* or *loudness* of musical tones depends (other things being equal) on the force and extent of the vibrations communicated by the sounding body to the medium which propagates them. This will diminish, however, with distance; which softens loud tones by lowering the intensity of the undulations, as a consequence of their more extensive diffusion. The cause of the differences in the *timbre*, or quality of musical tones,—such, for instance, as those which exist between the tones of a flute, a violin, a trumpet, and a human voice, all sounding a note of the same pitch,—are unknown: but they probably depend upon differences of *form* in the undulations. —Our ideas of the *direction* and distance of sounds, are for the most part formed by habit. Of the former we probably judge in great degree by the relative intensity of the impressions received by the two ears; though we may form some notion of it by a single ear, if the idea just stated as to the use of the semicircular canals (§ 952), be correct.—Of the *distance* of the sounding body, we judge by the intensity of the sound, comparing it with that which we know the same body to produce when nearer to us. The Ear may be deceived in this respect as well as the eye; thus the effect of a full band at a distance may be given by the subdued tones of a concealed orchestra close by us; and the Ventriloquist produces his deceptions, by imitating as closely as possible, not the sounds as they would be given-forth, but the sounds as they would strike our ears.

6. *Of the Sense of Sight.*

955. By the faculty of Sight we are made acquainted, in the first place, with the existence of *Light;* and by the medium of that agent, we take cognizance of the form, size, colour, position, &c., of bodies that transmit or reflect it. As to the mode in which luminous impressions are propagated through space, philosophers are not yet fully agreed; and the question is of no physiological importance, since all are agreed as to the *laws* which regulate their

transmission. These laws, which will be found at large in any Treatise on Natural Philosophy,* may be briefly stated as follows:—

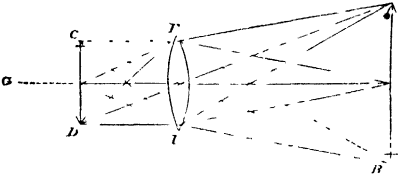
I. Light travels in straight lines, so long as the medium through which it passes is of uniform density.

II. When the rays of light pass from a rarer medium into a denser one, they are refracted *towards* a line drawn perpendicularly to the surface they are entering.

III. When the rays of light pass from a denser medium into a rarer one, they are refracted *from* the perpendicular.

IV. When rays proceeding from the several points of a luminous object at a distance, fall upon a double convex lens, they are brought to a focus upon the other side of it; in such a manner that an inverted picture of the object is formed upon a screen placed in the proper position to receive it. Thus in Fig. 175, A B is the object,

Fig. 175.



and E F the lens; the rays issuing from the two extremities and the centre of the object, are brought to a corresponding focus at a less distance on the other side of it, so as to form a distinct picture; but as the rays from A are brought to a focus at D, and those from B at C, the picture will be inverted.

V. The further the object is removed from the lens, the nearer will the picture be brought to it, and the smaller will it be; and *vice versâ*.

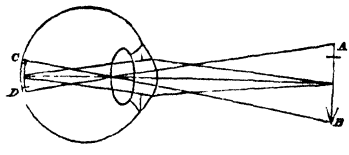
VI. If the screen be not held precisely in the focus of the lens, but a little nearer, or further-off, the picture will be indistinct; for the rays which form it will either not have met, or they will have crossed each other.

956. The Eye, in its most perfect form—such as it possesses in Man and the higher animals,—is an optical instrument of wonderful completeness; designed to form an exact picture of surrounding objects upon the Retina or expanded surface of the Optic nerve, by which the impression is conveyed to the brain. The rays of light which diverge from the several points of any object, and fall upon the front of the cornea, are refracted by its convex surface whilst passing through it into the eye, and are made to converge slightly.

* See Dr. Golding Bird's Manual, Chap. XIX.

They are brought more closely together by the crystalline lens, which they reach after passing through the pupil; and its refracting influence, together with that produced by the vitreous humour, is such as to cause the rays that issued from each point, to meet in a focus on the retina. In this manner, a complete inverted image is formed, as shown in Fig. 176; which represents a vertical section

Fig. 176.



of the eye, and the general course of the rays in its interior. As in the preceding figure, the rays which issue from the point A are brought to a focus at D; whilst those diverging from B are made to converge upon the retina at C.—The Retina, which is itself so thin as to be almost perfectly transparent, is spread over the layer of black pigment which lines the choroid coat. The purpose of this is evidently to *absorb* the rays of light that form the picture, immediately after they have passed through the retina; in this manner they are prevented from being reflected from one part of the interior of the globe to another, which would cause great confusion and indistinctness in the picture. Hence it is that in those *albino* individuals (both of the Human race, and among the lower animals) in whose eyes this pigment is deficient, vision is extremely imperfect, except in a very feeble light; for the vascularity of the choroid and iris is such as to give to these membranes a bright red hue, which enables them powerfully to reflect the light that reaches the interior of the eye, when they are not prevented from doing so by the interposition of the pigmentary layer.

957. The Eye is so constructed as to avoid certain errors and defects, to which all ordinary optical instruments are liable. One of these imperfections, termed *spherical aberration*, results from the fact that the rays of light passing through a convex lens whose curvature is circular, are *not all* brought to the same focus; those which have passed through the exterior of the lens being made to converge sooner than those which have traversed its central portion. The result of this imperfection is, that the image is deficient in clearness, unless only the central part of the lens be employed.—The other source of imperfection is what is termed *chromatic aberration;* and it results from the unequal degree in which the differently-coloured rays are refracted, so that they converge towards

different points. The violet rays, being the most refrangible, are soonest brought to a focus; and the red being the least refrangible, have their focus at the greatest distance from the lens. Hence it is impossible to obtain an image by an ordinary lens, in which the colours of the object are accurately represented; for the foci of its differently-coloured portions will be different; and its white rays will be decomposed, so that the outlines will be surrounded by coloured fringes.—The Optician is enabled to correct the effects of these aberrations, by combining lenses of different densities and curvatures, so arranged as to correct each other's errors, without neutralizing the refractive power. This is precisely the plan adopted in the construction of the Eye; which, when perfectly formed, and in a healthy state, forms an accurate picture of the object upon the retina, free from either spherical or chromatic aberration. This is effected by the combination of *humours* of different densities, having curvatures precisely adapted to the required purpose.

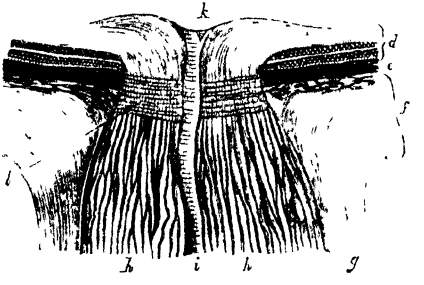
958. There are certain variations, however, in the conformation of the eye, the occurrence of which diminishes the perfection of its result. Thus the Cornea may be too convex, and the whole refractive power too great; so that the image of an object at a moderate distance is formed *in front* of the retina, instead of *upon* it. When this is the case, a distinct image can only be formed by bringing the object nearer to the eye; the effect of which will be, to throw the picture further back. Such an eye is said to be *myopic*, or 'short-sighted;' and its imperfection may be corrected by placing a concave lens in front of the cornea, of a curvature adapted to neutralize what is superfluous in the convexity of the latter.—On the other hand, if the cornea be too flat, and the refractive power of the humours be too low, the convergent rays proceeding from an object at a moderate distance will not meet *upon* the retina, but would meet *behind* it if allowed to pass-on; consequently the picture is indistinct, and it can only be made clear, either by withdrawing the object to a greater distance, which will bring the focus of the eye nearer to its front, or by interposing a convex lens to increase the refractive power of the eye. Such a condition is termed *presbyopic* (from its being common in aged persons), or 'long-sighted.' It may proceed to such an extent, that not even the removal of the object to *any* distance can permit the formation of a distinct picture; so that the assistance of a convex lens must be obtained, even to see remote objects clearly; though a less degree of convexity will be required, than for the clear vision of nearer objects. This state is particularly well-marked after the operation for cataract; for the removal of the crystalline lens so greatly diminishes the refractive power of the eye, as to render necessary the assistance of convex lenses of high curvature.

959. The power by which a healthy well-formed eye can accom-

modate itself to the distinct vision of objects at varying distances, is a very remarkable one; and its *rationale* is not yet properly understood. According to the laws already stated (§ 955, v. and vi.), the picture of a near object can only be distinct, when formed more remotely from the lens than the picture of a distant object. Consequently when the eye that has been looking at a distant object, and has seen it clearly, is turned to a near object, a distinct picture of the latter cannot be formed without some alteration, either in the distance between the refractive surfaces and the retina, or in the curvature of the former. It seems most probable that, in the Human eye, this adjustment is chiefly effected by the automatic contraction of the ciliary muscle; which, by drawing the lens nearer to the iris, will thus increase its distance from the retina. But this may not be the sole change.

960. The various humours and containing membranes of the Eye, thus answer the purpose of a most delicate and self-adjusting Optical instrument; the sole part which is immediately concerned in the reception of sensory impressions, being the Retina, or net-like expansion of the Optic nerve, which lies between the black pigment and the vitreous humour. The Optic nerve, near its entrance into the eye (Fig. 177), divides itself into numerous small fasciculi of ultimate fibrils, which are separated from each other by processes of the neurilemma that form what is known as the *lamina cribrosa* (*l*). After passing through this, the fasciculi appear to spread themselves out, and to inosculate with each other by an exchange of fibrils, so as to form a net-like plexus, which constitutes the

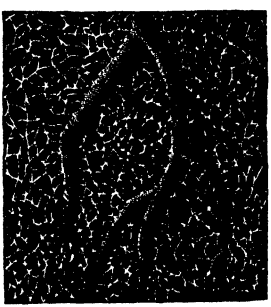
Fig. 177.*



* Vertical section of the coats of the Eye, at the point of entrance of the Optic Nerve:—*d*, retina; *e*, choroid; *f*, sclerotic; *g*, sheath of the optic nerve; *k*, fibres of the optic nerve; *i*, central artery of the retina; *k*, its point of subdivision; *l*, lamina cribrosa.

inner layer of the retina, or that in immediate contiguity with the vitreous humour. There is great difficulty, however, in the precise determination of the course of the nerve-fibres in the retina, on account of their minute size and the indistinctness of their characters. Externally to the stratum of nerve-fibres, which may be called the 'optic layer,' is a vesicular stratum, which consists of a finely-granular matrix, wherein are imbedded nerve-cells exactly resembling those of the Encephalon, and having, like them, a variable number of processes, some of which appear to become continuous with the peculiar fibres about to be described. It is to these fibrous and vesicular layers of the Retina, which together make-up the analogue of the cortical substance of the Cerebrum (§ 381), that the principal supply of blood is distributed by the minute capillary network (Fig. 178) which is spread-out through

Fig. 178.*



their substance: this having its origin in the ramifications of the *Arteria centralis retinæ*, which passes to the eye-ball through the centre of the optic nerve (Fig. 177, *ik*).—The principal part of the thickness of the Retina, however, is made-up of a series of layers (altogether forming 'Jacob's membrane'), which are chiefly composed of elongated 'rods' terminating in 'cones', so that the whole may be termed the 'bacillar' or staff-like structure. The general direction of these rods is *radial* as regards the globe of the eye, or *vertical* as regards any part of the surface of the membrane; yet there are situations in which the staff-like bodies are directed so obliquely, as to present quite an imbricated arrangement upon the external surface of the retina. Although the nature of the bacillar

* Distribution of Capillaries in vascular layer of Retina.

layer has not been yet fully elucidated, yet there appears adequate reason for regarding it as forming part of the true nervous structure, and as essentially concerned in the reception of sensory impressions. In the 'yellow spot of Soemmering,' which is situated in the exact centre of the retina, and is undoubtedly its most sensitive part, the layer of nerve-fibres derived from the optic nerve is entirely wanting, the retina being composed of the vesicular and bacillar layers alone. On the other hand, at the point at which the optic nerve enters the eye, the thickness of the retina is entirely made-up of the fibrous layer, the vesicular and bacillar layers being wholly deficient; and it can be shown by a simple experiment that this spot of the retina is insensible to visual impressions made upon it alone. Hence it is obvious that these impressions cannot act upon the nerve-fibres, save through the intermediation of the vesicles; and there seems much probability in the supposition of Professor Kölliker, that the 'rods' and 'cones' are nervous elements that are primarily concerned in the reception of luminous impressions, and that they communicate their condition to the vesicles by means of their delicate fibrous prolongations, and thence to the fibres of the optic nerve.—For the maintenance of the due nutrition of this apparatus, it is requisite that it should be occasionally called into use. If its functional power be destroyed, by opacity of the anterior portion of the eye, the nutrition of the retina and optic nerve suffers to such a degree, that these parts cease after a time to exhibit their characteristic structure; thus showing that the general rules already stated (CHAP. VII.) in regard to the connection between the functional activity and the due nutrition of tissues and organs, hold-good with respect to the Nervous structure.

961. The picture of external objects which is formed upon the Retina, closely resembles that which we see in a Camera Obscura. It represents the outlines, colours, lights and shades, and relative positions, of the objects before us; but these do not necessarily convey to the mind the knowledge of their real forms, characters, or distances. The perception of the latter, as already remarked (§ 936), is a *mental* process; and it may be *intuitive*, or *acquired*,—the latter, it would seem, being the general condition of the function in Man, the former in the lower animals. The infant is educating his perceptive powers, long before any indications present themselves of the exercise of higher mental faculties. By the combination, especially, of the sensations of sight and touch, he is learning to judge of the surfaces of objects as they *feel*, by the *appearance* they present,—to form an idea of their *distance*, by the mode in which his eyes are directed towards them,—and to estimate their *size*, by combining the notions obtained through the picture on the retina, with those he acquires by the movement of his hands over their different parts.—A simple illustration will show how closely the ideas excited by the two sets of sensations are blended in our minds.

The idea of *smoothness* is one which has reference to the touch; and yet it constantly occurs to us, on looking at a surface which reflects light in a particular manner. On the other hand, the idea of *polish* is essentially visual, having reference to the reflection of light from the surface of the object; and yet it would occur to us from the sensation conveyed through the touch, even in the dark.

962. That this sort of combination is not intuitive, in Man, but is the result of experience, is evident from the numerous observations that have been made upon individuals who had acquired the sense of Sight for the first time, after long familiarity with the characters of objects as perceived through the Touch. Thus a boy of four years old, upon whom the operation for congenital cataract had been very successfully performed, continued to find his way about his father's house, rather by *feeling* with his hands, as he had been formerly accustomed to do, than by his newly-acquired sense of sight; being evidently perplexed, rather than assisted, by the sensations which he derived through this. But when learning a new locality, he employed his sight, and evidently perceived the increase of facility which he derived from it. Among the many interesting particulars recorded of the youth on whom Cheselden operated with equal success, it is mentioned that, although perfectly familiar with a *dog* and a *cat* by feeling them, and quite able to distinguish between them by his sight, it was long before he associated his *visual* with his *tactile* sensations, so as to be able to name either animal by sight alone.—The question was put by Locke, whether a person born blind, who was able by his touch to distinguish a cube from a sphere, would, on suddenly obtaining his sight, be able to recognize each by the latter sense; the reply was given in the negative; and the experience of the cases just referred-to, as well as of many others, fully justifies such an answer.

963. Still there are, even in Man, certain intuitive perceptions, which afford great assistance in the formation of ideas regarding external objects through the visual sense. And the first of these is the power by which we recognize their erect position, notwithstanding the inversion of the image upon the retina. This is certainly not a matter of experience; nor is it capable of explanation (as some have thought) by a reference to the direction in which the rays impinge upon the retina, since objects are not seen in the direction in which the rays last fall upon the sensory surface. It is the *mind* which rectifies the inversion; and, as already remarked, it is just as difficult to understand how the inverted image on the retina should be taken-cognizance-of by the mind at all, as it is to comprehend how it should be thus rectified. In fact, there is no real connection whatever between the inversion of the image upon the retina, and that wrong perception of external objects which some have thought to be its necessary consequence. Any distortion of the picture, giving a wrong view of the *relative* positions of the

objects represented, would be attended with a different result.—The same may be said of the cause of the *singleness* of the sensation perceived by the mind, although an image is formed upon the retina of *each* eye, of those objects, at least, which lie in the field of vision that is common to both. This blending of the pictures formed upon the two retinæ, into a single perception, appears to be, in part at least, the effect of habit. For when the images do not fall upon those parts of the two retinæ which are accustomed to act together, *double vision* is the result. Thus if, when looking steadily at an object, we press one of the eye-balls sideways with the finger, we see two representations of the object; and the same thing frequently occurs, as a result of an affection of the nerves or muscles of one or both eyes (as in ordinary *strabismus* or squinting), or from some derangement in the nervous centres, as in various disorders of the Encephalon, and in intoxication. If this condition should be permanent, however, we usually find that the individual becomes accustomed to the double images, or rather ceases to perceive that they *are* double; probably because the mind becomes habituated to receive the impressions from the two parts of the retinæ which *now* act together. And if, after the double vision has passed-away, the conformity of the two eyes be restored (as by the operation for the cure for squinting), there is double vision for some little time, although the two parts of the retina which originally acted together are now brought into their pristine position.

964. But the images thus combined are far from being identical; and one of the most remarkable of all our perceptions, which, if not absolutely intuitive, is acquired at a very early period, is that by which they are reconciled and combined, and are caused to give rise to an idea that differs essentially from either image. No near object *can* be seen by the two eyes in the same manner: of this the reader may easily convince himself, by holding-up a thin book in such a position that its back shall be in a line with the nose and at a moderate distance from it; and by looking at the book, first with one eye, and then with the other. He will find that he gains a different view of the object with each eye, when used separately; so that if he were to represent it, as he actually sees it under these circumstances, he would have two perspective delineations differing from one another because drawn from different points of view. But on looking at the object with the two eyes conjointly, there is no confusion between these pictures; nor does the mind dwell upon either of them singly; but the union of the two intuitively gives us the idea of a solid *projecting* body,—such an idea as we could only have otherwise acquired by the exercise of the sense of touch. That this is really the case, has been proved by experiments with the very ingenious instrument, the Stereoscope, invented by Prof. Wheatstone; which is so contrived, as to bring to the two eyes, by reflection from mirrors, or by refraction through prisms or lenses,

two different pictures, such as would be accurate representations of a solid object as seen by the two eyes respectively. When the arrangement is such as to bring the images of these pictures to those parts of the retinæ, which would have been occupied by the images of the solid (supposing *that* to have been before the eyes), the mind will perceive, not one or other of the single representations of the object, nor a confused union of the two, but a body projecting in *relief*, the exact counterpart of that from which the drawings were made.—Thus the combination of the two pictures, and the perception of an object different from either of them, is effected by a mental process of an instinctive kind, of the nature of which we know nothing further.

965. When two pictures, representing *dissimilar* objects, are projected upon the retinæ of the two eyes by means of the Stereoscope, the result is a curious one. The mind perceives only one of them, the other being completely excluded for a time; but it commonly happens that, after one has been seen for a short period, the other begins to attract attention and takes its place, the first entirely disappearing; so that there is no confusion or intermingling of images, except at the moment of change. The Will may determine, to a certain extent, which object shall be seen; but not entirely; for if one picture be more illuminated than the other, it will be seen during a larger proportion of the time.—An interesting variation of this experiment may be made, without the aid of the Stereoscope, by holding a piece of blue glass before one eye, and a piece of yellow glass before the other. The result will be, not that everything will be seen of a green colour, but that the surrounding objects will be seen alternately blue and yellow; or sometimes the field of vision will be blue spotted with yellow, alternating with yellow spotted with blue. Thus, when we have two dissimilar objects before the eyes, our attention cannot be kept upon either, to the exclusion of the other, but is involuntarily directed either in part or completely, to one and the other alternately.

966. Our idea of the *distance* of near objects is evidently acquired from experience; and is suggested by the muscular sensations which are produced by the contraction of the adductor muscles of the eyes. When we direct our eyes towards a near object, a certain degree of convergence takes-place between their axes; the degree increasing as the distance between the object and the eyes diminishes, and *vice versâ*. We instinctively interpret the sensations thus produced, in such a manner as to be able to compare, with great accuracy, the relative distances of two objects that are not remote from the eyes. This intuition, however, is evidently one of the *acquired* kind; as may be seen by watching the actions of an infant, or of a person who has recently become possessed of Vision. When an object is held before the eyes, and an attempt is made to grasp it, the manner in which the attempt is made clearly shows that there is no power of

forming a precise idea of its situation, such as that which exists in many of the lower animals from their first entrance into the world (§ 938). The impressions made upon the eyes have to be corrected by those received through the touch, before the power of judging of distance is acquired. How much this power depends upon the conjoint use of *both* eyes, is evident from the difficulty with which any actions that require an exact appreciation of distance, are performed by those who have lost the sight of one eye, until they have acquired new modes of judging of it.

967. In regard to remote objects, we have not the same guide; since the convergence of the eyes in viewing them is so slight, that the axes are virtually parallel. Our judgment of *their* distance is chiefly founded upon their apparent size, if their actual size be known to us; and also upon the extent of ground which we see to intervene between ourselves and the object. But if we do not know their actual size, and are so situated that we cannot estimate the intervening space, we form our judgment chiefly from the greater or less distinctness of their colour and outline. Hence our idea of it will be very much affected by varying states of the atmosphere; a slight haziness increasing the apparent distance; whilst a peculiarly clear state of the air will seem to cause remote objects to approach much more closely. This want of convergence between the axes of the two eyes, has the further effect of causing the pictures upon the two retinæ to be nearly identical; and consequently the idea of *projection* is not so strongly excited; nor are we able to distinguish with the same certainty between a well-painted picture, in which the lights and shades are preserved, and the objects themselves in relief.

968. Our notion of the *size* of an object is closely connected with that of its distance. It is founded upon the dimensions of the picture projected on the retina; and the dimensions of this picture will vary, according to the laws of optics (§ 955, v.), inversely as the distance,—being, for example, twice as great when the object is viewed at the distance of one foot, as when it is carried to the distance of two feet. When we know the relative distances of two objects, the estimation of their real comparative sizes from their *apparent* sizes is easily effected by a simple process of mind; but this is not the case when we only guess at their distances; and our estimate of the size of objects even moderately remote, is as much affected by states of the atmosphere as is that of their distance,—the one being, in fact, proportional to the other. Thus a slight mist which gives the idea of increased distance, will also augment the apparent size; because in order that an object two miles off should produce a picture upon the retina of the same extent as that made by an object one mile off, it must have double the dimensions. It is evident that our perception of the size of objects must be *acquired* by experience, in the same manner as that of their distance has been shown to be.

969. We have now to consider briefly some other phenomena of Vision, in which the acts of Mind, that have been just alluded-to do not participate.—The contraction of the Pupil under the stimulus of light, seems to be effected by a sphincter muscle which surrounds the orifice, and which is put in action by a branch of the Third pair of nerves. This is an action with which the *will* has nothing to do; and it takes-place entirely without our consciousness. Although it is due to the stimulus of light, yet there is reason to believe that the consciousness of the presence of light is not requisite; and that it is, therefore, an excito-motor action. The Optic nerve seems to be the channel through which the impression is conveyed to the nervous centres, whilst the Third pair is that through which the motor impulse is conveyed to the iris; but there is some ground for the idea that the Fifth pair may in some degree convey the requisite stimulus, when the optic nerve has been divided. That the *dilatation* of the pupil is a muscular action, appears from the fact that the *radiating* fibres of the iris are of the same character with the *circular;* both sets constituting, in Man, a peculiar variety of the non-striated form of muscular tissue. The stimulus to this action is conveyed through the branches of the Sympathetic system which pass through the ophthalmic ganglion; and by the division of the sympathetic of either side high up in the neck, a permanent contraction of the pupil is induced, a temporary dilatation being effected by a galvanic stimulus to the upper or cephalic extremity of the divided sympathetic trunk. The contraction of the pupil is evidently destined to exclude from the interior of the eye, such an amount of light as would be injurious to it; whilst its dilatation in opposite circumstances admits the greatest possible number of rays. There is a contraction of the pupils, however, which takes-place without any change in the amount of light. This occurs when the two eyes are made to converge strongly upon any object brought very near them; and its purpose appears to be, to prevent the rays from entering the eye at such a wide angle, as would render it impossible for them to be all brought to their proper foci, and would thus produce an indistinct image.

970. In the use of the Eye, like that of the Ear, there is a tendency to blend into one continuous image a succession of luminous impressions made at short intervals; upon which fact depend a number of curious optical illusions. The length of the greatest interval that can elapse without an interruption of the presence of the image (in other words the duration of the visual impression), may be measured by causing a luminous object to whirl round, and by ascertaining the longest period that may be allowed for each revolution, consistently with the completeness of the circle of light thus formed. By experiments of this kind, the time has been found to vary in different individuals or in different states of the same individual, from about 1-4th to 1-10th of a second; that is,

the impression must be repeated from four to ten times in each second, to ensure the continuousness of the image.

971. The impressions of variety of *colour*, are produced by the differently-coloured rays which objects reflect or transmit to the eye. It is curious that some persons, whose sight is perfectly good for forms, distances, &c., are unable to discriminate colours. This curious affection has received the name of Daltonism: from the circumstance that the celebrated Dalton was an example of it. There are numerous modifications of it; the want of power to discriminate colour being total in some, whilst in others it extends only to certain shades of colour, or to the complementary colours.

972. When the retina has been exposed for some time to a strong impression of some particular kind, it seems less susceptible of feebler impressions of the same kind; thus if we look at any *brightly-luminous* object, and then turn our eyes upon a sheet of paper, we shall perceive a *dark* spot upon it; the portion of the retina which had received the brighter image, not being affected by the fainter one.—Again, when the eyes have received a strong impression from a *coloured* object, the spot which is seen when the eyes are directed upon a white surface exhibits the *complementary* colour; for the retina has been so strongly affected, in the part that originally received the image, by its vivid hue, that it does not perceive the fainter hue of the same kind in the object to which it is then turned, and it is impressed only by the remaining rays forming the complementary colours. This explanation applies to the phenomena of the coloured shadows which are often seen at sunset, and of those which may be seen in a room whose light enters through coloured glass or drapery. For if the prevailing light be of one colour,—orange or red for instance,—the eye will not take cognizance of that colour in the faint light of the shadows; and will see only its complement, blue or green. If the shadow be viewed through a tube, in such a manner that the general coloured ground is excluded, it presents the ordinary tint.

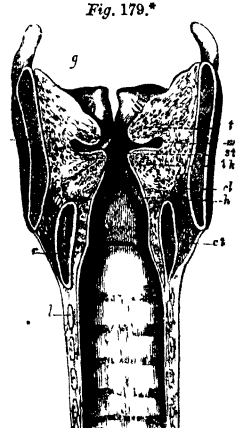
CHAPTER XIV.

OF THE VOICE AND SPEECH.

973. THERE is one particular application of Muscular power in Man, which deserves special consideration, as being that by which he effects his most complete and intimate communication with his fellows;—that, namely, by which his organ of Voice is put into action. In all air-breathing Vertebrata, the production of sound depends upon the passage of air through a certain portion of the

respiratory tubes, which is so constructed as to set it in vibration, as it passes forth from the lungs.—In Reptiles, the vibrating apparatus is situated at the point where the trachea opens into the front of the pharynx; it is of very simple construction, however, being only composed of a slit bounded by two contractile lips; and few of the animals of this class can produce any other sound than a *hiss*, which, owing to the great capacity of their lungs, is often very much prolonged.—In Birds, the situation of the vocal organ is very different. The trachea opens into the front of the pharynx, as in Reptiles, by a mere slit; the borders of which have no other movement than that of approaching one another, so as to close the aperture when necessary. This appears to be the instrument for regulating the ingress and egress of air, in conformity with the wants of the *respiratory* function. The *vocal* larynx of Birds is situated at the lower extremity of the trachea, just where it subdivides into the bronchial tubes; and it is of very complex construction, especially in the singing birds.—In Mammalia, on the other hand, the vocal organ and the regulator of the respiration are united in one larynx, which is situated at the top of the trachea. There are few, if any, of this class, which have not some vocal sound; but the variety and expressiveness which can be given to it, differ considerably in the several orders; being by far the greatest in Man, who, alone, there is reason to believe, has the power of producing articulate sounds, or proper *language*.

Fig. 179.*

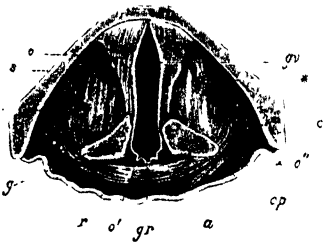


974. The Larynx is built-up, as it were, upon the *Cricoid* cartilage (Figs. 179, 180, *r*), which surmounts the trachea, and which might be considered as its highest ring modified in form, its depth from above downwards being much greater posteriorly than anteriorly. This is embraced, as it were, by the Thyroid cartilage (*s*); which is articulated to the sides of the Cricoid by its lower horns, round the extremities of which it may be considered to rotate, as

* Vertical section through the middle of the Human Larynx, in a direction transverse to that of the vocal cords.—*l*, rings of the trachea; *r*, cricoid cartilage; *s*, thyroid cartilage; *g*, arytenoid cartilage; *t*, superior or false vocal cords; *m*, ventricle of the larynx; *st*, inferior or true vocal cords; *th*, thyro-arytenoideus muscle; *cl*, crico-arytenoideus lateralis; *cr*, crico-thyroideus; *h*, mucous membrane lining of the larynx.

on a pivot. In this manner the front of the *Thyroid* cartilage may be lifted-up or depressed by the muscles which act upon it, whilst the position of its posterior part is but little changed. Upon the upper surface of the back of the Cricoid cartilage, are seated the two small *Arytenoid* cartilages (*g*); these are so tied to the cricoid

Fig. 180.*



by a bundle of strong ligaments, as to have a sort of rotation upon an articulating surface, which enables them to be approximated-to or separated-from each other; their inner edges being nearly parallel in the first case, but slanting away from each other in the second. To the summit of these cartilages are attached the *Chordæ vocales* or vocal ligaments (*s t*), composed of yellow fibrous or elastic tissue. These stretch across to the front of the Thyroid cartilage; and it is upon their condition and relative situation, that the absence or the production of vocal tones, and all their modifications of pitch, depend. They are rendered tense by the depression of the front of the Thyroid cartilage, and relaxed by its elevation; by which action the *pitch* of the tones is regulated.

975. During the ordinary acts of inspiration and expiration, the Chordæ vocales appear to be widely separated from each other, and to be in a state of the freest possible relaxation. In order to produce a vocal sound, not only must they be made to approach one another, but their inner faces must be brought into parallelism, both of which ends are accomplished by the rotation of the Arytenoid cartilages; whilst, at the same time, they must be put into a certain degree of tension, by the depression of the Thyroid cartilage.

* Transverse section of the Larynx just above the Vocal Cords and the bases of the Arytenoid Cartilages —*o*, *o'*, *o''*, mucous surface of the glottis; *r*, cricoid cartilage; *s*, thyroid cartilage; *g*, arytenoid cartilage; *th*, thyro-arytenoideus muscle; *a*, arytenoideus transversus; *cp*, crico-arytenoideus posticus · *cl*, crico-arytenoideus lateralis; *, divided fibres of the thyro-epiglotticus; *gc*, vocal glottis; *gr*, respiratory glottis.

Both of these movements take place consentaneously, and are mutually adapted to each other; the vocal ligaments being approximated, and the rima glottidis consequently narrowed, at the same time that their tension is increased. There is a certain aperture which is favourable to the production of each tone, although the pitch itself is governed by the tension of the Vocal Cords; and it is, perhaps, to a want of consent between the two, that the peculiarly discordant nature of some voices, which appear incapable of producing a distinct musical tone, is due.—Even when the edges of the vocal cords are most closely approximated, as in the production of a high note, the posterior part of the rima glottidis (Fig. 180, *gr*) remains nearly as open as it is when the cords are separated from each other so as to widen the anterior part of the fissure; and hence it appears that the anterior portion of the glottis (*g v*) is especially subservient to vocalization, and the posterior (*g r*) to respiration.

976. Thus there are two sets of movements concerned in the act of vocalization;—the regulation of the relative position of the Vocal Cords, which is effected by the movements of the Arytenoid cartilages;—and the regulation of their tension, which is determined by the movements of the Thyroid cartilage. The Arytenoid cartilages are made to diverge from one another by means of the *Crico-arytenoidei postici* of the two sides (*c p*), which proceed from their outer corners and turn somewhat round the edge of the Cricoid, to be attached to the lower part of its back; their action is to draw the outer corners of the Arytenoid cartilages outwards and downwards, so that the points to which the vocal ligaments are attached are separated from one another, and the rima glottidis is thrown open. The action of these muscles is antagonized by that of the *Arytenoideus transversus* (*a*), which draws together the Arytenoid cartilages; and by that of the *Crico-arytenoidei laterales* of the two sides (*cl*), which run forwards and downwards from the outer corners of the Arytenoid cartilages and tend by their contraction to bring together their anterior points, to which the Vocal ligaments are attached.—The depression of the front of the Thyroid cartilage, and the consequent tension of the Vocal ligaments, are occasioned by the conjoint action of the *Crico-thyroidei* (*ct*) of the two sides, which causes the Thyroid and Cricoid cartilages to rotate the one upon the other, at the articulation formed by the inferior cornua of the former; and this action will be assisted by the *Sterno-thyroidei*, which tend to depress the front of the Thyroid cartilage, by pulling from a fixed point below. On the other hand, the elevation of the front of the Thyroid cartilage, and the relaxation of the Vocal ligaments, are effected by the contraction of the *Thyro-arytenoidei* of the two sides (*th*), whose attachments are the same as those of the Vocal ligaments themselves; and this is aided by the *Thyro-hyoidei*, which will tend to draw up the front of the Thyroid cartilage, acting from a fixed point above.

977. The muscles which govern the aperture of the Glottis,—those namely, which separate and bring-together the arytenoid cartilages, and thus widen or contract the space between the posterior extremities of the vocal ligaments,—have important functions in connection with the Respiratory actions in general; standing as guards, so to speak, at the entrance to the lungs. We can entirely close the glottis, through their means, by an effort of the Will, either during inspiration or expiration; and it is a spasmodic movement of this sort which is concerned in the acts of Coughing and Sneezing, the purpose of which is to expel, by a sudden and powerful blast of air, any irritating substances, whether solid, liquid, or gaseous, which have found their way into the air-passages. These muscles appear to be under the sole direction of the *inferior* or *recurrent* laryngeal nerve, which seems to possess exclusively *motor* endowments. When this nerve is divided, on each side, or when the Par Vagum is divided above its origin, the muscles of the larynx (with the exception of the crico-thyroid) are paralyzed; and the aperture of the glottis may remain open, or may be entirely closed, according to the manner in which its lips are affected by the currents of air in egress or ingress. It is found that, under such circumstances, *tranquil* respiration may be carried-on; but that any violent ingress or egress of air will tend to drive the lips of the glottis (these being in a state of complete relaxation) into apposition with each other, so as completely to close the aperture. The character of the *superior* laryngeal nerve appears to be almost exclusively *afferent;* no muscle, except the crico-thyroid, being thrown into contraction when it is irritated; whilst, on the other hand, if it be divided, neither the act of coughing, nor any reflex respiratory movement whatever, can be excited by irritating the lining membrane of the larynx.

978. It has been fully proved, by the researches of Willis, Müller, and others, that the action of the Vocal ligaments, in the production of sound, bears no resemblance to that of vibrating *strings;* and that it is not comparable to that of the mouth-piece of the *flute*-pipes of the Organ: but that it is, in all essential particulars, the same with that of the *reeds* of the Hautboy or Clarionet, or the *tongues* of the Accordion or Concertina. All the phenomena attending the production of Musical tones are fully explicable on this hypothesis; except the production of *falsetto* notes, which has not yet been clearly accounted-for.—The power which the Will possesses, of determining, with the most perfect precision, the exact degree of tension which these ligaments shall receive, is extremely remarkable. Their average length in the Male, in the state of repose, is estimated by Müller at about 73-100ths of an inch; whilst, in the state of greatest tension, it is about 93-100ths; the whole difference, therefore, is not above 20-100ths, or one-fifth of an inch. In the female glottis, their average dimensions are about 51-100ths

and 63-100ths, respectively; so that the difference is here only 12-100ths, or less than one-eighth, of an inch. Now the natural compass of the voice, in most persons who have cultivated the vocal organ, may be stated at about two octaves, or 24 semitones. Within each semitone, a singer of ordinary capability could produce at least ten distinct intervals; so that, for the total number of intervals, 240 is a very moderate estimate. There must, therefore, be at least 240 different states of tension of the vocal cords, every one of which can be at once determined by the will, when a distinct conception exists of the tone to be produced (§ 905); and, as the whole variation in their length is not more than one-fifth of an inch, even in Man, the variation required, to pass from one interval to another, will not be more than 1-1200th of an inch.—And yet this estimate is much below that which might be truly made from the performance of a practised vocalist. The celebrated Madame Mara is said to have been able to sound 50 different intervals between each semitone; the compass of her voice was at least 40 semitones, so that the total number of intervals was 2000. The extreme variation in the length of the vocal cords, even taking the larger scale of the Male larynx, not being more than one-fifth of an inch, it may be said that she was able to determine the contractions of her vocal muscles to the *ten-thousandth* of an inch.

979. It is on account of the greater length of the Vocal cords, that the *pitch* of the voice is much lower in Man than in Woman; but this difference does not arise until the end of the period of childhood; the size of the larynx being about the same in the Boy and Girl up to the age of 14 or 15 years, but then undergoing a rapid increase in the former, whilst it remains nearly stationary in the latter. Hence it is that Boys, as well as Girls and Women, sing either *treble* or *alto*; whilst Men sing *tenor*, which is about an octave lower than the treble, or *bass*, which is about an octave lower than the alto. The cause of the variation in the *timbre* or *quality* in different voices, is not certainly known; but it appears to be due, in part, to differences in the degree of flexibility and smoothness of the cartilages of the larynx. In women and children, these cartilages are usually soft and flexible, and the voice is clear and smooth; whilst in men, and in women whose voices have a masculine roughness, the cartilages are harder, and are sometimes almost completely ossified. The *loudness* of the voice depends in part upon the force with which the air is expelled from the lungs; but the variations in this respect which exist among different individuals, seem partly due to the degree in which its resonance is increased by the vibration of the other parts of the larynx, and of the neighbouring cavities. In the Howling Monkeys of America, there are several pouches opening from the larynx, which seem destined to increase the volume of tone that issues from it; one of these is excavated in the substance of the hyoid bone itself. Although these Monkeys

are of inconsiderable size, yet their voices are louder than the roaring of lions, and are distinctly audible at the distance of two miles; and when a number of them are congregated together, the effect is terrific.

980. The vocal sounds produced by the action of the larynx are of very different characters; and may be distinguished into the *cry*, the *song*, and the ordinary or acquired *voice*. The cry is generally a sharp sound, having little modulation or accuracy of pitch, and being usually disagreeable in its *timbre* or quality. It is that by which animals express their unpleasing emotions, especially pain or terror; and the Human infant, like many of the lower animals, can utter no other sound.—In *song*, by the regulation of the vocal cords, definite and sustained musical tones are produced, which can be changed or modulated at the will of the individual. Different species of Birds have their respective songs; which are partly instinctive, and partly acquired by education. In Man, the power of song is entirely acquired; but some individuals possess a much greater facility in acquiring it than others,—this superiority appearing to depend upon their more precise conception of the tones to be sounded, as well as their more ready imitation, independently of differences in the construction of the larynx itself. The larynx of an accomplished vocalist, obedient to the expression of the emotions, as well as to the dictates of the will, may be said to be the most perfect musical instrument ever constructed.—The *voice* is a sound more resembling the cry, in regard to the absence of any sustained musical tone; but it differs from the cry, both in the quality of its tone, and in the modulation of which it is capable by the will. In ordinary conversation, the voice passes through a great variety of musical tones, in the course of a single sentence or even a single word, sliding imperceptibly from one to another; and it is when we attempt to fix it definitely to a certain pitch, that we change it from the *speaking* to the *singing* tone.

981. The power of producing *articulate* sounds, from the combination of which *Speech* results, is altogether independent of the Larynx; being due to the action of the muscles of the mouth, tongue, and palate. Distinctly-articulate sounds may be produced without any vocal or laryngeal tone, as when we *whisper*; and it has been experimentally shown that the only condition necessary for this mode of speech, is the propulsion of a current of air through the mouth from back to front. On the other hand, we may have the most perfect laryngeal tone without any articulation; as in the production of musical sounds not connected with words. But in ordinary speech, the laryngeal tone is modified by the various organs which intervene between the larynx and the os externum. The simplest of these modifications is that, by which the *Vowel* sounds are produced; these sounds being continuous tones, modi-

fied by the form of the aperture through which they pass-out. Thus, let the reader open his mouth to the widest dimensions, depress the tongue, and raise the velum palati, so as to make the exit of air as free as possible; on then making a vocal sound, he will find that this has the character of the vowel *a* in *ah*. On the other hand, if he draw-together the lips, still keeping the tongue depressed, he will pass to the sound represented in the English language by *oo*, in the Continental language by *u*. By attention to the production of other vowel sounds, it will be found that they are capable of being formed by similar modifications in the form of the buccal cavity and the size of the buccal orifice; and that they are capable of being sustained for any length of time. There is an exception, however, in regard to the sound of the English *i*, as in *fine;* which is, in reality, a diphthongal sound, produced in the act of transition from a peculiar indefinite murmur to the sound of the long *e*, which takes its place when we attempt to continue it. The short vowel sounds, moreover, such as *a* in *fat*, *e* in *met*, *o* in *pot*, &c., are not capable of being perfectly prolonged; as they require, for their true enunciation, to be immediately followed by a consonant.—A tolerably-good artificial imitation of Vowel sounds has been effected, by means of a reed-pipe representing the larynx, surmounted by an India-rubber ball, with an orifice, representing the cavity and orifice of the mouth. By modifying the form of the ball, the different vowels can be sounded during the action of the reed.

982. In the production of the sounds termed *Consonants*, the breath suffers a more or less complete interruption in its passage through the parts anterior to the larynx. The most natural primary division of these sounds, is into those which require a total stoppage of the breath at the moment previous to their being pronounced, and which, therefore, cannot be prolonged; and those in pronouncing which the interruption is partial, and which can, like the vowel-sounds, be prolonged indefinitely. The former have received the designation of *explosive* consonants; the latter are termed *continuous*.—In pronouncing any consonants of the *explosive* class, the posterior nares are completely closed; and the whole current of air is directed through the mouth. This may be checked by the approximation of the lips, as in pronouncing *b* and *p;* by the approximation of the point of the tongue to the front of the palate, as in pronouncing *d* and *t;* or by the approximation of the middle of the tongue to the arch of the palate, as in pronouncing the hard *g* or *k*. The difference between *b*, *d*, and *g*, on the one hand, and *p*, *t*, and *k*, on the other, depends simply upon the greater extent of the meeting surfaces in the former case than in the latter.—In sounding some of the *continuous* consonants, the air is not allowed to pass through the nose; but the interruption in the mouth is incomplete; this is the case with *v* and *f*, *z* and *s*. In others, the posterior nares are not closed, and the air has a nearly

free passage, either through the nose alone, as in *m* and *n*, or through the nose and mouth conjointly as in *l* and *r*. The sound of *h* is a mere aspiration, caused by an increased force of breath; and that of the guttural *ch*, as it exists in Welsh, Gaelic, and most Continental languages, is an aspiration modified by the elevation of the tongue, which causes a slight obstruction to the air, and an increased resonance in the back of the mouth.

983. The study of the mode in which the different Consonants are produced, is of particular importance to those who labour under defective speech, especially that difficulty which is known as *Stammering*. This very annoying impediment is occasioned by a want of proper control over the muscles concerned in Articulation; which, instead of obeying the Will, are sometimes affected with an involuntary or spasmodic action, that interrupts the pronunciation of particular words,—just as, in Chorea, the muscles of the limbs are interrupted by spasmodic twitchings, in the performance of any voluntary movement. In fact, persons affected with general Chorea frequently stammer; showing that ordinary Stammering may be considered as a kind of local Chorea. The analogy between the two states is further indicated by the corresponding influence of excited Emotions in aggravating both.—It is in the pronunciation of the consonants of the *explosive* class, that the stammerer usually experiences the greatest difficulty; for the total interruption to the breath, which they occasion, is frequently continued involuntarily; so that either the expiration is entirely checked, the whole frame being frequently thrown into the most distressing semi-convulsive movements, or the sound comes-out in jerks. Sometimes, however, the spasmodic action occurs in the pronunciation of *vowels* and *continuous* consonants; the stammerer prolonging his expiration, without being able to check it.

984. The best method of curing this defect (where there is no malformation of the organs of speech, but merely a want of power to use them aright), is to study the particular difficulty under which the individual labours; and then to cause him to practise systematically the various movements concerned in the production of the sounds in question, at first separately, and afterwards in combination,—until he feels that his voluntary control over the muscles is complete. The patient would at first do well to practise sentences from which the explosive consonants are omitted; his chief difficulty, arising from the spasmodic suspension of the expiratory movement, being thus avoided. Having mastered these, he may pass-on to others, in which the difficult letters are sparingly introduced; and may finally accustom himself to the use of ordinary language. One of the chief points to be aimed-at, is to make the patient feel that he *has* command over his muscles of articulation; and this is best done, by *gradually* leading him from that which he *can* do, to that which he fears to attempt.

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