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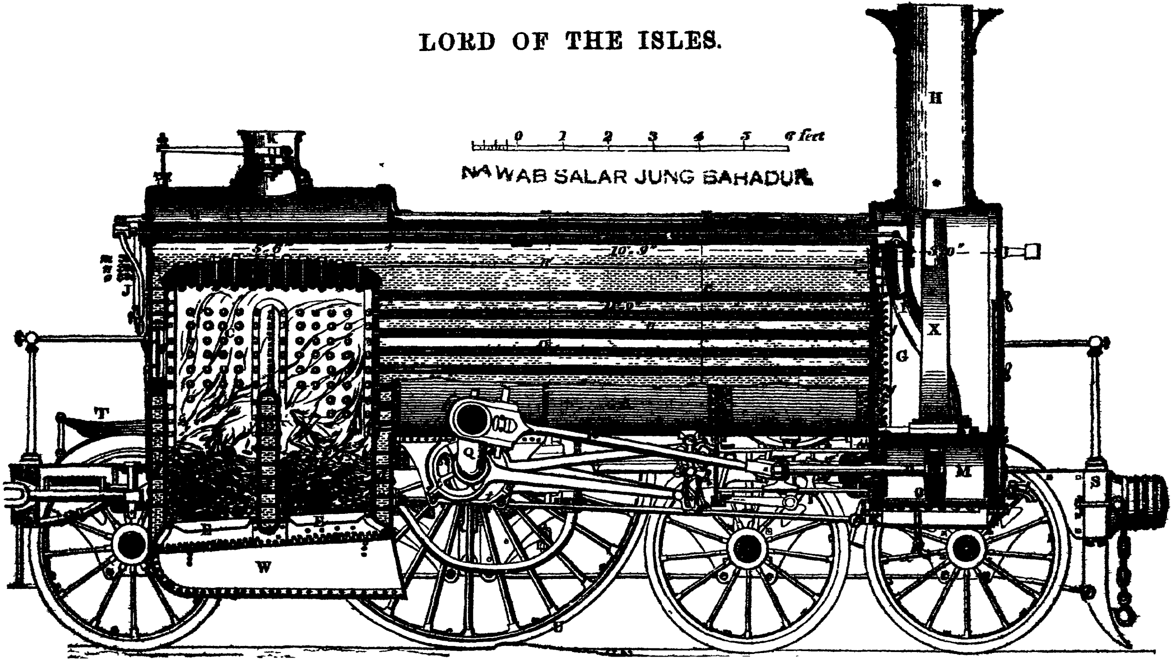

NAWAB SALAR JUNG BAHADUR

ELEMENTARY TREATISE

ON

STEAM AND LOCOMOTION;

BASED ON THE PRINCIPLE OF

CONNECTING SCIENCE WITH PRACTICE, IN A POPULAR FORM.

With Illustrations.

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PREFACE.

The increasing extension of steam-power leads to an extending desire to become conversant with its economical production and employment. True economy is however slowly realised by practice alone, as is testified by the history of many important inventions, as well as by that of the steam-engine; but when science and practice harmoniously co-operate, progress is greatly accelerated. In steam locomotion it is an every-day duty to generate and employ steam; but it requires the joint aid of both science and practice to decide whether these two distinct processes are or are not economically performed. In drawing inferences from observed facts, practice is powerfully assisted by a scientific knowledge of the natural agents it has to deal with, and the properties of their compounds. In steam locomotion the natural agents are water, fuel, heat, and metals. The compounds are combustion and steam. Science points out the composition of water, of fuel, and the heat-transmitting power of metals. It also acquaints us with the properties of steam, and the process of combustion. Practice observes facts corroborative or corrective of theories, and improves the mechanism, until, in the example of a locomotive engine, every pulsation of the escaping steam is evidence of the successful union of science and practice.

The importance of such union, and the absence of early scientific education in a very large portion of the community, have led us to give a popular digest of the properties of water, fuel, heat and steam, with remarks on combustion and the manufacture of coke, as essential preliminaries to either true locomotion or even domestic economy. This digest is accompanied by valuable classified tables of the mechanical, combustible, and chemical characteristics of 168 varieties of

British and Foreign coals, derived principally from the important researches conducted at the Museum of Practical Geology. This attempt to combine theory and practice is a plan strongly recommended by Sir H. De la Beche, Dr. Whewell, Dr. Lyon Playfair, and other eminent men of science, as necessary to progress; also in the excellent philosophical work on Mathematical Physics, written by John Herepath, Esq.

To promote such progress, and convey popular information on steam locomotion, is the design of this treatise, of which the first or theoretical part is now published. The second part, containing familiar descriptions of modern locomotive engines, will shortly follow. In a third part it is proposed to give a succinct historical outline of locomotive engines, with their connection with the eldest branch of the steam family noticed by Hero as "ancient" some 150 years before our era.

It is intended to add to the third volume a copious index that shall be useful for reference to the great variety of subjects treated of in the work.

To M. Morin, Director-General of the Conservatoire des Arts et Métiers, of Paris; Daniel Gooch, Esq., C. E.; Joseph Glynn, Esq., F. R. S.; Goldsworthy Gurney, Esq.; James Hann, Esq.; J. Herepath, Esq.; Seymour Clarke, Esq.; John Gray, Esq., M.D.; E. J. Dent, Esq.; J. Hackworth, Esq.; F. Trevethick, Esq.; A. Torry, Esq.; J. Deurance, Esq.; W. Buckle, Esq.; Hyde Clarke, Esq.; and other practical gentlemen who have placed information at the Author's service, he begs to return his grateful thanks.

There is much valuable knowledge floating amongst practical men, which would be useful if collected and arranged.

Information, therefore, on any point connected with the history or improvement, either of past or modern locomotives, from any one, will be duly acknowledged, as contributions to an accurate history of steam locomotion, that honour may be given to whom honour is due.

Dec. 1, 1851. JOHN SEWELL.

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ON

STEAM AND LOCOMOTION.

SECTION I.

CHAPTER I.

STEAM.

STEAM is pure water expanded by heat into an invisible vapour. The first practical step is to obtain the water, and the next to apply the heat to produce steam power.

That a power such as this is, which displays some of its force in ordinary domestic operations, should have arrested the attention of early philosophers to its capabilities is as natural a sequence of the new form given to water by heat, as that the steam from a tea-kettle should have pointed one of Dickens's Christmas tales. Its employment in philosophical experiments, and also by the priests of early ages to maintain their ascendency over the minds of the people is matter of history, but the exact period of its first introduction appears to be unknown. The most ancient account of its performances now extant is a treatise published by Hero of Alexandria, about 150 years before our era, or nearly 2000 years ago. In this treatise he described amongst the inventions of others, some of his own (which will be described in their place), and these have gained him the honour of being regarded as the first inventor of the steam engine, and Egypt as the land of its origin.

To understand the nature of steam, it is desirable to possess a knowledge of its component parts. Familiar as are these component bodies, water and heat, yet each of them has formed the subject of elaborate researches, and each of them yet excites interest; the water, as to its composition, and the heat as to its nature.

Taking them in their order of forming steam, the following summary of the generally received opinions regarding them will, it is trusted, prove interesting.

Composition of Water.

This well-known fluid is the basis of the weight and materiality of steam.

In its ordinary state water is a fluid covering a very large portion of the globe, performing most important duties. It is not only abundant as a fluid, but, united with other bodies, it forms a large proportion of animal and vegetable matter, for analyists tell us that potatoes contain 75 per cent., turnips 90 per cent., a beef steak 80 per cent., and a man 75 per cent. of water. Chemically, they tell us that, a man of 10 stone would be made up of 105 lbs. of water, and 35 lbs. of carbon and nitrogen, and that $\frac{5}{6}$ths of his daily food is water.

It has been general since Watt's discovery of the composition of water to define it as consisting of one volume of oxygen and two volumes of hydrogen, or by weight, 1 part of hydrogen and 8 parts of oxygen, the specific gravity of the latter being 16 times that of the former.

It is usual to prove this theory of the composition of water by burning or exploding these two gases in a glass vessel, when water is deposited equal in weight to that of the decomposed gases. It has, however, been suggested that the force required to compress these gases into water must also find some electrical agent in them so as to produce their marked compression in volume. For water is nearly 30 times heavier than oxygen, 478 times heavier than hydrogen, and 34 times heavier than air.

The discovery of the composition of water has been ascribed by some to Watt, and by others to Cavendish. Lord Brougham, in his Discourse on Natural Theology, states, "Having examined the evidence, I am convinced Watt was the first discoverer in point of time." This being regarded as one of the greatest discoveries of the age, was naturally a point of emulation amongst those having the least chance of gaining such honour, and it has by no mean authority been awarded to Watt.

Science, however, both in America and in Belgium, has again aroused attention to the decomposition of water, and to the various economical uses to whichit may be applied.

About twenty years ago, Macvicar, of St. Andrews, called attention to the particles, or atoms, constituting hydrogen as being of the simplest forms, and that water might either be all hydrogen, or partly oxygen, partly hydrogen, as the atoms were in a more or less divided state. He regarded the hydrogen atom as the elementary one, and that electrical affinity combined these atoms in a variety of ways, to form oxygen, water, or other substances. These views received little notice at the time, but they are now apparently confirmed by the reported discoveries of Mr. Payne, of America.

These discoveries, if fairly established, are of great importance, and merit a short description of this mode of decomposing water to obtain heat, light, and power.

According to Mr. Payne's experiments, water can be converted into hydrogen, or oxygen, without any appearance of the other gas, or both gases can be produced at once. This is effected by a magneto-electric machine, with two horseshoe magnets, about 12 inches long, placed horizontally on a frame, but the one 4 inches higher than the other. Between the ends of these magnets, two *helices* are set in rapid motion by a wheel. In the construction of the helices the greatly increased power is said to be obtained. They are not formed of solid wire, as is usual, but of copper strips wound round spirally so as to form a hollow wire in which water can be confined. This wire is insulated by means of India rubber or gutta percha. Faraday has demonstrated that a small quantity of water will contain a vast quantity of electricity, so that it is inferred that as the water power of the helices is increased to induce or receive the electric current, so is the power increased to give it off.

The manner of applying the power so obtained is as follows:—In an open vessel of water is placed a common bell glass, reaching within 4 inches of the bottom of the vessel. The top of this glass is fitted with a brass cap for admitting the wires for connecting it with another jar of spirit of turpentine, when it is required for illumination. After passing through this cap of the first jar, the wires terminate in a cylindrical box 1½ inches long by 1 inch diameter, perforated with small holes round the top part. In this box are the *electrodes* or points of connection of the poles, and here is the point of danger from the intensity of the force evolved by the helices.

The turpentine jar has also a cap fitted to it for connecting it with the water jar, and also with a gas burner.

It is stated that hydrogen only is produced by the action of the negative electricity, and oxygen only by positive electricity; but when both kinds of electricity are used, both oxygen and hydrogen are evolved. The interruption of the alternate current is said to be effected by immersing the broken ends of the wire in a glass of water, without being in contact, leaving the broken wire less active. For illumination the hydrogen is passed through the turpentine, when it becomes "catalized," and burns with great brilliancy.

From this it is inferred that hydrogen is a gas and negative electricity, and oxygen the same gas and positive electricity, and that water is, therefore, either all hydrogen, or all oxygen, or partly both, according to the electricity employed in decomposing it. The cost of production is said to be so small that either as a power or as a combustible it will exercise great economical influence.

The editor of the "Boston Chronotype," who appears to have seen the whole process gone through, states, "The power of the helices to the mechanical combination of the machine, is comparatively as the force of water in moving a large water wheel is to the force required to raise the water gate." He also distinctly warns experimenters to be guarded as to the power evolved in the electrode, lest it should prove uncontrollable with serious results, for each discharge of the helices produces a numerous crop of bubbles of gas in the water. These bubbles are a singular and important coincidence with the globules formed by ordinary heat in generating steam, which will be further noticed under that head.

Trials by our own electricians are said to have failed, yet M. Nollet, of Brussels, has just patented in England his improved plan and the use of the gases as a motive power similar to steam in the atmospheric engine.

Power of Water.

Simple as may be the appearance of water, it forms a most valuable part of creation, and in each of its characters, of a solid, as ice; of a fluid, as water; or of a vapour, as steam, it developes immense power. It is at its greatest density about 40° Fah. but does not become solid until 32°, when its expansive force is exhibited in the disintegration of rocks, bursting of pipes, or fracturing other bodies in which it may be confined, as practically tested in the following trials made in the Arsenal at Warsaw, in 1828-9, for the purpose of ascertaining the expansive force of water in a state of freezing.

For this purpose cast-iron howitzer shells, 6 in. 8 lines diameter, having a thickness of metal 1 in. 2 lines, and an orifice, or opening of 1 in. 2 lines diameter, were employed. One of these shells having a capacity of 46·29 cubic in. was filled with water at 40° Fah. and with the orifice open exposed to the atmosphere at 21° Fah. In two hours a column of ice 2 in. 2 lines long was projected from the opening, which was the greatest effort made, and gave an expansive force of 2·31 cub. in. or about $\frac{1}{20}$th part of the whole volume, or 5 per cent.

A second shell was filled, and the orifice closed with a piece of wood driven into it. It was then exposed as before, when the plug was expelled, and ice occupied its place.

A third shell was filled, and the orifice closed with an iron screw, having through it a hole 3 lines diameter. After two hours' exposure the shell was burst into two unequal parts, the smaller being thrown 10 feet, and the larger part thrown 1 foot from the spot it was placed upon. The ice had formed only 6 lines thick, the remainder being still fluid. A fourth shell was filled, plugged, and exposed at 28° in a similar manner, with a hole of 6 lines diameter, and also burst in two parts, one of them being thrown a distance of 4 feet. The ice was 13 lines thick, the rest fluid. A fifth shell was filled, plugged up solidly, and exposed at 28°, when it burst as before, and the smallest piece was thrown a distance of one foot. The thickness of the ice was only 5 lines.

These will convey some definite idea of the expansive power of water in a freezing state, which is supposed to be derived from the re-arrangement of the crystalizing particles in angles of 60° or 120° to each other, requiring more space than when in a fluid state, and thus resisting confinement.

In giving motion to machinery, water, from its uniform action, has long been held in deserved repute. It has been attempted to be made the means of keeping up a regular power by a given quantity of water raised by a steam engine, and then giving motion to an overshot water wheel. The following table will show that the best constructed water wheels yet used do not exceed 80 per cent. of the full weight of water, consequently to employ steam power to raise another power, and then to lose 20 per cent. of the power so raised was the reverse of economy, and has, of course, been abandoned.

Of the water employed on the different wheels the useful effect is for

The	Undershot Wheel	from	27 to 33	per cent.
„	Breast „	„	45 „ 52	„
„	Overshot „	„	60 „ 80	„
„	Re-action or Turbine		56 „ 78	„

It may be explained that the undershot wheel is used when a fall is not obtainable, and the water only acts by its force against the float at the extremity of the arms. The breast wheel is employed where there is more fall, and the water enters the buckets, and acts by its weight. The overshot wheel is general where there is sufficient fall to carry the water over its top, and allow it to act on the opposite side, both by its force and weight. The turbine is of modern invention, where the water enters the arms of the wheel from a central tube, and issues by orifices at their extremities, but on opposite sides. The force of the issuing water being thus unbalanced, or flowing in one direction only, causes the arms to revolve in contrary directions. As now improved both in this country and on the Continent, these wheels are in considerable repute for economy of power and space. Gwyne's newly patented modification of the turbine and bucket wheel is said to generate 85 per cent. of the power employed. In all these wheels the weight of water is as its contents multiplied by its gravity of 10 lbs. each imperial gallon, but its force or pressure is as its height. Thus comparatively a column of water 34 ft. high, a column of air the entire height of the atmosphere, and a column of mercury 30 in. high are all equal in weight. That weight is nearly 14¾ lbs. avoirdupois.

The following table, by Fenwick, of the power of an overshot water wheel, a wind mill, and a steam engine, will be useful for reference:—

Table No. 1.

COMPARATIVE EFFECT OF MOTIVE POWERS.

WATER, acting on a 10-foot wheel, per min.	STEAM. Diameter of Cylinder.		HORSES, each 12 hours, at a rate of 2 miles per hour.	MEN, each 12 hours per day.	WIND. Radius of Sails.			POWER, — 1000 lbs. raised per minute.
	Old Class	Improved Class.			Common.	Dutch.	Smeaton's.	
Lbs.	Inch.	Inch.	No.	No.	Feet	Feet.	Feet.	Feet.
2,300	8	6·12	1	5	21·21	17·89	15·65	13
3,900	9·5	7·8	2	10	30·01	25·30	22·13	26
5,280	10·5	8·2	3	15	36·80	30·98	27·11	39
6,600	11·5	8·8	4	20	42·18	35·78	31·3	52
7,900	12·5	9·35	5	25	47·50	40·	35·	65
9,700	14·	10·55	6	30	52·03	43·82	38·34	78
11,700	15·4	11·75	7	35	56·90	47·33	41·41	91
13,500	16·8	12·8	8	40	60·09	50·60	44·27	104
14,550	17·3	13·6	9	45	63·73	53·66	46·96	117
15,840	18·5	14·2	10	50	67·17	56·57	49·50	130
17,400	19·4	14·8	11	55	70·46	59·33	51·91	143
19,000	20·2	15·2	12	60	73·59	61·97	54·22	156
21,000	21·	16·2	13	65	76·59	64·5	56·43	169
23,000	22·	17·	14	70	79·49	66·94	58·57	182
25,000	23·1	17·8	15	75	82·27	69·28	60·62	195
26,860	23·9	18·3	16	80	84·97	71·55	62·61	208
28,700	24·7	19·	17	85	87·07	73·32	64·16	221
30,550	25·5	19·6	18	90	90·13	75·90	67·41	234
32,400	26·2	20·1	19	95	92·60	77·98	68·23	247
34,260	27·	20·7	20	100	95·	80·	70·	260
37,500	28·5	22·2	22	110	99·64	83·9	73·42	286
40,000	29·8	23·	24	120	104·06	87·63	75·68	312
44,600	31·1	23·9	26	130	108·32	91·22	79·81	338
48,500	32·4	24·7	28	140	112·20	94·66	82·82	364
52,500	33·6	25·5	30	150	116·35	97·98	85·73	390

Forcing Power of Water.

Water forms a remarkable exception to the general law of expansion by heat, for it is more bulky when only 32° than when it is 8° hotter, or 40° temperature. Being then at its greatest density, and almost incompressible, it is made to develop its immense power in Bramah's hydraulic presses, whereby the strength of cables, anchors, iron, and other materials is tested, goods packed, and other operations performed requiring great force.

One of its most recent performances in this field was lifting the Conway and Britannia tubular bridges, up 100 ft. into their places. The weight of the largest tube being about 1800 tons, and one end lifted at a time, gave about 900 tons as the weight to be raised at once. This was done by a strong cast-iron cylinder, 11 in. thick, with a solid piston, or ram 20 in. in diameter and 6 ft. stroke, working through a water-tight stuffing box or gland, now to be seen in the Industrial Exhibition. Into this cylinder the water was forced through a half-inch pipe by a pump of $1\frac{1}{16}$ in. diameter worked by a 40-horse steam engine. The power would therefore be as the areas of the ram and pump were to each other, or as 1 to 355. The pressure on the ram would then be 900 tons, or

$$\frac{900 \times 2240 \text{ (lbs. water)}}{314{\cdot}16 \text{ (area of piston)}} = 6417 \text{ lbs. pressure for}$$

each square inch of the head of the ram.* The action may be thus explained: water is slowly forced into the cylinder by the pump, and being very nearly incompressible, as soon as the vacant space in the cylinder is filled, it gradually impels the ram outwards, with a force measured by the resistance against the external end of the ram, and limited by the strength of the cylinder and power of the pump to force in the water.

Weight and Measure of Water.

As a liquid, water is made the standard of comparison of the specific weight or gravities of other liquids and solids. At 55° fah. a cubic foot of water weighs 998·74 ounces avoidupois, but for facility in calculations it is generally taken as 1000 ounces, and the imperial gallon is fixed at 160 ounces, or 10 lbs. avoirdupois of distilled water. By weight a cubic foot of water is taken as $62\frac{1}{2}$ lbs., and by this data the cubic contents in feet of any water tank or boiler multiplied by $62\frac{1}{2}$ gives the weight of water in lbs. avoirdupois, and these

* For an interesting description of these bridges, see Rudimentary Treatise on Iron Girder Bridges.

lbs. divided by 10 give the number of gallons. Thus if the water space in a boiler be 60 cubic ft. it will contain 3750 lbs. or 375 gallons of water, for

$$60 \times 62{\cdot}5 = 3750 \text{ lbs. and } \frac{3750}{10} = 375 \text{ gallons.}$$

The standard fixed by Parliament for the Imperial gallon being 10 lbs. avoirdupois, at a temperature of 62 Fah. the following table gives the weight of a gallon of water at each degree of temperature from 32° to 80° :

Table No. 2.

WEIGHT OF A GALLON OF WATER AT VARIOUS TEMPERATURES.

Deg Fah.	Lbs. Avoir.	Deg. Fah.	Lbs. Avoir.	Deg Fah.	Lbs. Avoir.
80	9·9777	63	9·9989	47	10·0099
79	9·9792	62	10·0000	46	10·0102
78	9·9806	61	10·0010	45	10·0105
77	9·9820	60	10·0019	44	10·0107
76	9·9834	59	10·0027	43	10·0109
75	9·9848	58	10·0035	42	10·0111
74	9·9861	57	10·0043	41	10·0112
73	9·9874	56	10·0050	40	10·0113
72	9·9887	55	10·0057	39	10·0113
71	9·9900	54	10·0064	38	10·0113
70	9·9912	53	10·0070	37	10·0112
69	9·9924	52	10·0076	36	10·0111
68	9·9935	51	10·0082	35	10·0109
67	9·9946	50	10·0087	34	10·0107
66	9·9957	49	10·0091	33	10·0104
65	9·9968	48	10·0095	32	10·0101
64	9·9979				

This shows that from the point of greatest density (38° to 40°) it expands equally in both ways, becoming gradually lighter per gallon. Sea water has its greatest density at the freezing point.

For calculating the quantities of water contained in either cylindrical or rectangular vessels, the following approximate exponents of the relative weights and measures of water at its ordinary temperature will be useful.

For Cylindrical Vessels or Boilers.

Water.

Cyl. in.		Diam. length.		Lbs. avr.		Imp. gal.
1	or	1	× 1 =	·02842	or	·00284
12	or	1	× 12 =	·341	or	·034
1728	or	1 cyl. ft.	=	19·1	or	4·91
2·282 cyl. ft.			=	1 cwt.	or	11·2
45·64 cyl. ft.			=	1 ton	or	224·

352·97	cyl. in.	=	1	gal.
1·273	,,	=	1	cubic in.
1·	,,	=	·7854	,,

To find the capacity of any other cylinder, multiply the square of its diameter by its length, and the product by the exponent of the unit of the feet or inches in which the dimensions may be taken. For elliptical vessels or boilers multiply the longest by the shortest diameter, and by the length for the capacity in cylindrical inches, and the product by the required exponent.

For concentric spaces add together the inner and outer diameters, and multiply the sum by the difference of these diameters, and by the length for the capacity in cylindrical inches, which being multiplied by the tabular exponent will give the required quantity.

Spherical Vessels.

	lbs. avr.	gal. imp.	
A globe of water 1 in. diam. =	·0189 or	·001888	or 1 spherical inch.
A globe of water 12 in. diam. =	32·75 or	3·263	or 1 spherical foot.

To find the capacity of any other sphere multiply the cube of its diameter by the required exponent of unity of the dimensions taken in feet or inches.

Rectangular and Cubical Vessels.

Water.

Cub. in.		Sq. length.		Lbs avr.		Imp. gal.
1	or	1 × 1	=	·03617	or	·00361
12	or	1 × 12	=	·434	or	·0434
1728	or	1 cub. ft.	=	62·5	or	6·25
		1·8 cub. ft.	=	1 cwt.	or	11·2
		35·84 ,,	=	1 ton	or	224·
		277·274 cub.in.	=	1 imp. gal.		
		·1 ,,	=	1·273 cyl. in.		
		·7854 ,,	=	1· ,,		

The cubical contents of any other rectangular vessel may be found by multiplying the length, width and depth together, and their product by the requisite exponent.

Table No. 3.

AREAS OF THE SEGMENTS OF A CIRCLE,

Whose diameter is one, and divided into 1000 *equal or* 500 *parts for each half of the circle.*

Hght	Area Seg.	Hght	Area Seg	Hght	Area Seg	Hght	Area Seg.	Hght	Area Seg.
·001	·000042	·022	014322	043	·011734	·064	·021168	·085	·032186
·002	·000119	·023	·004618	·044	·012142	·065	·021659	·086	·032745
·003	.000219	·024	·004921	·045	·012554	·066	·022154	·087	·033307
·004	·000337	·025	·005230	·046	012971	·067	·022652	·088	·033872
·005	·000470	·026	·005546	·047	013392	·068	·023154	·089	·034441
·006	·000618	·027	.005867	·048	·013818	·069	·023659	·090	·035011
·007	·000779	·028	·006194	·049	·014247	·070	·024168	·091	·035585
·008	·000951	·029	·006527	·050	·014681	·071	·024680	·092	·036162
·009	·001135	·030	·006865	051	·015119	·072	·025195	·093	·036741
·010	·001329	·031	·007209	·052	·015561	·073	·025714	·094	·037323
·011	·001533	·032	·007558	·053	·016007	·074	·026236	·095	·037909
·012	·001746	·033	·007913	·054	·016457	·075	·026761	·096	·038496
·013	·001968	·034	008273	·055	·016911	·076	·027289	.097	·039087
·014	·002199	·035	·008638	056	·017369	·077	·027821	·098	·039680
·015	·002438	·036	·009008	·057	·017831	·078	·028356	·099	·040276
·016	·002685	·037	·009383	058	·018296	·079	·028894	·100	·040875
·017	·002940	·038	·009763	·059	·018766	·080	·029435	·101	·041476
·018	·003202	·039	·010148	·060	·019239	·081	·029979	·102	·042080
·019	·003471	040	·010537	·061	·019716	082	·030526	·103	·042687
·020	·003748	·041	·010931	·062	·020196	·083	·031076	·104	·043296
·021	·004031	·042	·011330	·063	·020680	·084	·031629	·105	·043908

Hght	Area Seg	Hght	Area Seg.	Hght	Area Seg.	Hght	Area Seg.	Hght	Area Seg.
·106	·041522	·154	·076746	·202	·113426	·250	·153546	·298	·196337
·107	·045139	·155	·077469	·203	·114230	·251	·154412	·299	·197252
·108	·045759	·156	·078194	·204	·115035	·252	·155280	·300	·198168
·109	·046381	·157	·078921	·205	·115842	·253	·156149	·301	·199085
·110	·047005	·158	·079649	·206	·116650	·254	·157019	·302	·200003
·111	·047632	·159	·080380	·207	·117460	·255	·157890	·303	·200922
·112	·048262	·160	·081112	·208	·118271	·256	·158762	·304	·201841
·113	·048894	·161	081846	·209	·110083	·257	·159636	·305	·202761
·114	·049528	·162	·082582	·210	·119897	·258	·160510	·306	·203683
·115	·050165	·163	·083320	·211	·120712	·259	·161386	·307	·204605
·116	·040804	·164	·084059	·212	·121529	·260	·162263	·308	·205527
·117	·051446	·165	·084801	·213	·122347	·261	·163140	·309	·206451
·118	·052090	·166	·085544	·214	·123167	·262	·164019	·310	·207376
·119	·052736	·167	·086289	·215	·123988	·263	·164899	·311	·208301
·120	·053385	·168	·087036	·216	·124810	·264	·165780	312	·209227
·121	·054036	·169	·087785	·217	·125634	·265	·166663	·313	·210154
·122	·054689	·170	·088535	·218	·126459	·266	·167546	·314	·211082
·123	·055345	·171	·089287	·219	·127285	·267	·168430	·315	·212011
·124	·056003	·172	·090041	·220	·128113	·268	·169315	316	·212940
·125	·056663	·173	·090797	221	·128942	·269	·170202	·317	·213871
·126	·057326	·174	·091554	·222	·129773	·270	·171089	·318	·214802
·127	·057991	175	·092313	·223	·130605	·271	·171971	·319	·215733
·128	·058658	·176	·093074	·224	·131438	·272	·172867	·320	·216666
·129	·059327	·177	·093836	·225	·132272	·273	·173758	·321	·217599
·130	·059999	·178	·094601	·226	·133108	·274	·174649	·322	·218533
·131	·060672	·179	·095366	·227	·133945	·275	·175542	·323	·219468
·132	·061348	·180	·096134	·228	·134784	·276	·176435	·324	·220404
·133	·062026	·181	·096903	·229	·135624	·277	·177330	·325	·221340
·134	·062707	·182	·097674	·230	·136465	·278	·178225	·326	·222277
·135	·063389	183	·098447	·231	·137307	·279	·179122	·327	·223215
·136	·064074	·184	·099221	·232	·138150	·280	·180019	·328	·224154
·137	·064760	·185	099997	·233	·138995	·281	·180918	·329	·225093
·138	·065449	186	·100774	·234	·139841	·282	·181817	·330	·226033
·139	066140	·187	·101553	·235	.140688	·283	182718	331	·226974
·140	·066833	188	·102334	·236	·141537	·284	·183619	·332	·227915
·141	067528	·189	·103116	·237	·142387	·285	·184521	·333	·228858
·142	068225	·190	·103900	·238	·143238	·286	·185425	·334	·229801
·143	068924	·191	·104685	·239	·144091	·287	·186329	·335	·230745
·144	·069625	·192	·105472	·240	·144944	·288	·187234	·336	231689
·145	·070328	·193	·106261	·241	·145799	·289	·188140	·337	·232634
·146	·071033	·194	·107051	·242	·146655	·290	·189047	·338	·233580
·147	·071741	·195	·107842	·243	·147512	·291	·189955	·339	·234526
·148	·072450	·196	·108636	·244	·148371	·292	·190864	·340	·235473
·149	·073161	·197	·109430	·245	·149230	·293	·191775	·341	·236421
·150	·073874	·198	·110226	·246	·150091	·294	192684	·342	·237369
·151	·074589	·199	·111024	·247	·150953	·295	·193596	·343	·238318
·152	·075306	·200	·111823	·248	·151816	·296	·194509	·344	·239268
·153	·076026	·201	·112624	·249	·152680	·297	·195422	·345	240218

Hght	Area Seg	Hght	Area Seg	Hght	Area Seg.	Hght	Area Seg.	Hght	Area Seg.
·346	·241169	·377	·270951	·408	·301220	·439	331850	·470	·362717
·347	·242121	·378	271920	·409	·302203	·440	·332843	·471	·363715
·348	·243074	·379	272890	·410	·303187	·441	·333836	·472	·364713
·349	·244026	380	273861	·411	·304171	·442	·334829	·473	·365712
·350	·244980	·381	·274832	·412	·305155	·443	·335822	·474	·366710
·351	·245934	·382	·275803	·413	·306140	·444	336816	·475	·367709
·352	·246889	·383	·276775	414	·307125	·445	·337810	·476	·368708
·353	·247845	·384	277718	·415	·308110	·446	·338804	·477	·369707
·354	·248801	·385	·278721	·416	·309095	·447	·339798	·478	·370706
·355	·249757	·386	279691	·417	·310081	·448	·340793	·479	·371704
·356	·250715	·387	·280668	418	·311068	·449	·341787	·480	372704
·357	·251673	·388	·281642	·419	·312054	·450	·342782	·481	·373703
·358	·252631	·389	·282617	·420	313041	·451	·343777	·482	·374702
·359	·253590	·390	·283592	·421	·314029	·452	·344772	·483	·375702
·360	·254550	·391	·284568	·422	·315016	·453	·345768	·484	·376702
·361	·255510	·392	·285544	·423	·316001	·454	·346764	·485	·377701
·362	·256471	·393	·286521	·424	·316992	·455	·347759	·486	·378701
·363	·257433	·394	·287498	·425	317981	·456	·348755	·487	·379700
·364	·258395	·395	·288476	·426	·318970	·457	·349752	·488	·380700
·365	·259357	·396	·289453	·427	·319959	·458	·350748	·489	·381699
·366	·260320	·397	·290432	·428	·320948	·459	·351745	·490	·382699
·367	·261284	·398	·291411	·429	·321938	·460	·352742	·491	383699
·368	·262248	·399	292390	·430	·322928	·461	·353739	·492	·384699
·369	·263213	·400	293369	·431	·323918	·462	·354736	·493	·385699
·370	·264178	·401	·294349	·432	·324909	·463	·355732	·494	·386699
·371	·265144	·402	·295330	433	·325900	·464	·356730	·495	·387699
·372	·266111	·403	·296311	·434	·326892	·465	·357727	·496	·388699
·373	·267078	·404	·297292	·435	·327882	·466	·358725	·497	·389699
·374	·268045	·405	·298273	·436	·328874	·467	·359723	·498	·390699
·375	·269013	·406	·299255	·437	·329866	·468	·360721	.499	.391699
·376	·269982	·407	·300238	·438	·330858	·469	·361719	.500	·392699

PROBLEM,

To find the Area of a Segment of a Circle.

RULE.—Divide the height, or versed sine, by the diameter of the circle, and opposite the quotient in the column of heights.

Take out the area, in the column on the right hand, and multiply it by the square of the diameter, for the area of the segment.

EXAMPLE.—Required the area of a segment of a circle, whose height is 9 inches, and the diameter of the circle 58 inches.

$9 \div 58 = \cdot 155$ and opposite $\cdot 155 = \cdot 07747 \times 58^2 = 261 \cdot 5$ sq. in. $\times\ 1 \cdot 273 = 331$ cubic inches, as the required area.

In calculating the separate contents of a cylindrical boiler, segmental spaces require to be measured, and for this purpose the foregoing tabular area of 500 segments or one half of a circle whose diameter is 1, or unity, will be useful. The areas are in square measure, which requires to be multiplied by 1·273 for circular inches.

The following practical examples will show how part of these exponents may be usefully applied to ascertain very nearly the quantity of water which is in any boiler or tender, or other vessel.

EXAMPLE 1.—Taking the dimensions of the Lord of the Isles' locomotive boiler to be as under, required the quantity of water in tons and in gallons which would fill it to the water line 9 inches below the top of the cylindrical part of the boiler.

Dimensions.

CYLINDRICAL PART, 11 ft. long by 58 in. diameter, containing 303 tubes, each 2 in. external diameter, and 10 iron stay rods each $1\frac{1}{4}$ in. diameter. Steam space a segment of the top of this part whose height or versed sine is 9 in.

FIRE BOX PART, 71 in. wide, 66 in. long, and 63 in. mean depth,
less inside fire box, 64 ,, 60 ,, ,, 63 ,, ,,
leaving water spaces.

Front and back	71 in. wide,	63 in. deep,	and 3 in.	mean space.
Two sides, each	60 in. long,	63 in. ,,	and $3\frac{1}{2}$ in.	,, ,,
Top of fire box	69 in. wide,	9 in. ,,	and 66 in.	long.
Partition	63 in. ,,	51 in. ,,	and 4 in.	space.

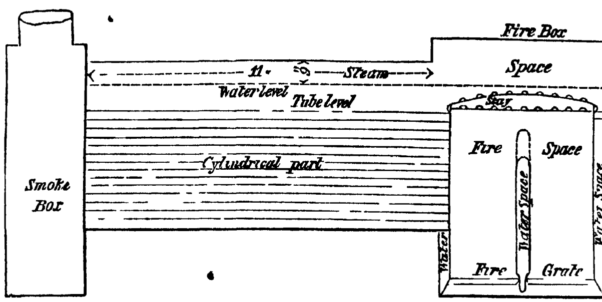
Less.

	″	″	″	Cir. in.
Fire door	21 ×	18 ×	3 tubes	= 1212 × 3, in. long.
12 stays	$1\frac{1}{2}$ ×	$6\frac{1}{2}$ ×	60, 10 stay rods $1\frac{1}{4}$ diam.	× 66 in. long.

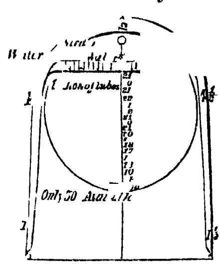
Steam space, a segment of the top of the fire box whose height or versed sine is 15 inches of a circle 71 inches diameter.

Boiler.

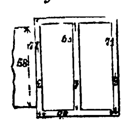
Longitudinal Section.



Transverse Section of Fire Box.



Plan of Fire Box.



These three diagrams will give an outline of the internal arrangement of the water, fire, and steam spaces in the Lord of the Isles' locomotive boiler.

Fig. No. 1 is a longitudinal section, showing the front and back water spaces between the outside shell of the boiler and inside fire-box. The transverse central water space which reaches up to the level of the fire door in the centre, and higher at the sides is also shown. The fire-box is thus divided into two rectangular spaces, whose flat sides are strongly secured by numerous copper stays to the outside shell to resist the force of the steam. From the smallness of the diagrams these stays are not shown, but only one of the strong wrought-iron stays necessary to support the flat top of the fire-box, 303 tubes each, 11 ft. long, by 2 inches external diameter convey the heated gases from the fire to the chimney, usually placed on the top of the smoke box. The line of the water level shows the comparative depth of the sectional steam and water spaces, whilst the line of the tubes and top of the fire-box shows the heating space.

Fig. No. 2 is a transverse sectional view of the fire-box, showing the two side water spaces between the inside and outside boxes, which are also strongly secured together by copper stays. The complete circle shows the area of the cylindrical part of the boiler, and the larger circle the area of the fire-box outside shell. The water line shows the comparative steam space in each of these parts.

Fig. No. 3, is a plan of the fire-box, showing how the circulation of the water spaces is arranged, and which spaces communicate with the cylindrical part below the tubes, as shown in Fig. 1.

From these dimensions we have for the cylindrical parts:

		Cir. in.
Sectional area of boiler $= 58^2$		$= 3364$
	Cir. in.	
less tubular area of 303 tubes $\times 2^2 =$ . .	1212	
and segmental steam space,		
$= \frac{9}{58} = \cdot 155 = \cdot 07747$ (tab. num.) $\times 58^2 = 260$ sq. in. $\times 1\cdot 273 =$	331	1543
Leaving a sectional water area of		1821

which multiplied by the length $= 1821 \times 132 = 240372$ cy. in.
The tubular space $= 1212$ area $\times 132$ length $= 159981$ cy. in.
The steam space $= 331$ area $\times 132$ length $= 43692$ cy. in.

For the fire box or rectangular parts we have

					Cub. in.
Front and back spaces	= 71 in. ×	63 in. deep ×	3 in. wide ×	2	= 26838
Side spaces	= 60 in. ×	63 in. deep ×	$3\frac{1}{2}$ in. wide ×	2	= 26460
Partition spaces	= 63 in. ×	51 in. deep ×	4 in. wide ×	1	= 12852
Top of fire box	= 66 in. ×	9 in. deep ×	69 in. wide ×	1	= 40986
					107136

Deduct for back tubes = 1212 cub. in. × 3 × ·7854	= 2856	
For front fire door = 21 × 18 × 13	= 1134	
For stays of sides, ends, and partitions, $\frac{1}{10}$ of space	= 4131	
For top of box stays $\frac{1}{5}$ of water space	= 8193	= 16317
		90819

Or by taking the space included within the outside fire box, and deducting the inside one, thus,

Outside box = 71 wide × 66 long × 63 deep	= 295218
Less inside box = 64 wide × 60 long × 63 deep	= 241920
	53298
Add partition and top as above	= 53838
	107136
Less deductions as above	16317
Total water space round fire box	= 90819

Steam space $=\frac{15}{71}=\cdot211=\cdot120713$ (tab. num.) $\times 71^2=609$ sq. in. area, and 609 × 66 length = 40014 sq. in. steam space on top of fire box.

Summary.

Steam Space.

	Cub. in.	Cy. in.	or	Cub. in.
Cylindrical part =		43692 × ·7854		= 34315
Fire box part =	40014 × 1·273	= 50938 ×		= 40014
Total steam space		94630	or	74329

Compared with the capacity of the cylinders

$$=18 \text{ in. diameter by } 24 \text{ in. stroke} = 18^2 \times 24 = \frac{94630}{7776} = 12\cdot17$$

times the capacity of 1 cylinder, or 6 times the capacity of the two cylinders.

Water Space.

	Cub. in.	Cy. in.	or	Cub. in.
Cylindrical part	=	240372 × ·7854		=188788
Fire box part	= 90819 × 1·273	=115612		= 90819
	Total water space	=355984	or	279607.

Cyl. in.	Lbs.	Lbs. av.		Gals. imp. t. c. q. lb.
And 355984 × ·02842	= $\frac{10117}{2240}$	=4·516 tons,	or	4 10 1 7
and 355984 × ·00284		=1011·7 gallons of water.		

And by cubic measure,

Cub. in.	Lbs.	Lbs. av.		t. c q. lb.
279607 × ·03617	= $\frac{10113}{2240}$	=4·514,	or	4 10 1 3
and 279607 × ·00361		=1011·3 gallons,		

being a difference of 4 lb. on the whole quantity, arising from the exponents being approximate and not strictly correct, but sufficiently near for practical purposes.

Heating Space.

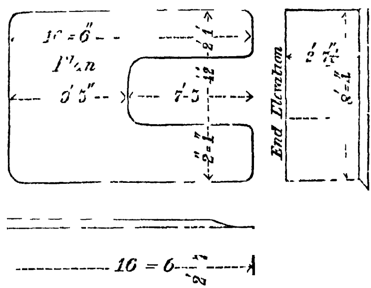
	Cub. in.	Cy. in.	or	Cub. in.
Tubular space	=	159984 × ·7854		=125651
Fire box	= 241920 × 1·273	=307964		=241920
	Total heating space	=467948	or	367571.

Tabular Abstract of Boiler Contents.

		Cy. in.		Cub. in.	Ratio.	Per cent.
Steam space	=	94630	or	74329	1	10·3
Water space	=	355984	or	279607	3·73	38·75
Heating space	=	467948	or	367571	4·94	50·95.

EXAMPLE 2.—Taking the dimensions of the tender water tank of the Lord of the Isles, locomotive engine, as under, required the quantity of water it will contain in lbs., in tons, and in gallons?

Tender Tank.



Length, 16′ 6″; width, 8′ 4″; depth, 2′ 7½″; less coke space, 7′ 3″ long, and 4′ 2½″ wide and 2′ 7½″ deep.

	Cub. In.		Cub. Ft.
178″ × 100″ × 31·5″ =	523700	÷ 1728 =	360·9
less 87″ × 50″ × 31·5″ =	137025	÷ 1728 =	79·3
	486675		281·6.

Cub. In. Lb.
and 486675 × ·03617 = 17603 lbs.
which divided by 2240 = 7 tons, 17 cwt., 0 qr., 18 lbs.
for gallons 486675 × ·00361 = 1760 gallons,
or 281·6 cube ft. × 6·25 = 1760 gallons.

Abstract of Tender Contents.

	Cub. In.	Ratio.	Per cent.
Coke space	137025	1	18
Water space	623700	4·55	82.

Impurities of Water.

Since nothing but pure water is converted into pure steam, and the impurities of water are either deposited on the boiler, or, by the action of chemical agents, partly carried away in the steam, to the detriment of slide-valves, and pistons; the following table will convey an idea of the impurities in well, river, and canal water.

All the London waters are from Professor Brande's Report. The New Swindon water is by Dr. Herapath, the eminent chemist, of Bristol.

Table No. 1.

IMPURITIES IN ONE GALLON OF WATER.

(70,000 grains = 1 imperial gallon.)

		Grains.		Per cent.
Thames at Greenwich		27·9	Average, 23·2 or ·0033.	·00398
" London Bridge		28·		·004
Westminster		24·4		·0035
Brentford		19·2		·00274
Twickenham		22·4		·0032
Teddington		17·4		·0025
New River		19·2		·002
Colne		21 3		·00304
Lea		23·7		·00338
Ravensborne, at Deptford		20·		·00285
Combe and Delafield's Well,	deep	56·8		·0081
Apothecaries' Hall, Blackfriars	"	45·		·00613
Notting Hill	"	60·6		·00865
Royal Mint	"	37·8		·0054
Hampstead Water Works	"	40·		·00571
Berkeley Square	"	60·		·00857
Tilbury Fort	"	75·		·01071
Goding's Brewery	"	50·		·00714
"	shallow	110·		·01571
More's Brewery, Old Street	deep	38·9		·005557
"	shallow	110·		·0157
Trafalgar Square fountains	deep	68·9		·00984
St. Paul's Churchyard	"	75·		·01071

	Grains.	Per cent.
Bream's Buildings	115·	·01643
St. Giles, Holborn	105·	·015
St. Martin's, Charing Cross	95·	·01357
Postern Row, Tower	98·	·014
Artesian Well at Grenelle, Paris	9·86	·
New Swindon Canal, filtered	32·16	·00014

Of these a detailed analysis of the Royal Mint water, by Professor Brande, and of the New Swindon filtered canal water, by W. Herapath, Esq., of Bristol, will show the nature of these impurities.

In one gallon of water from the Royal Mint well there were—

Proximate saline components.	*Grains.*
Chloride of sodium	10·53
Sulphate of soda	13·14
Carbonate of soda	8·63
" of lime	3·5
" of magnesia	1·5
Silicia	0·5
Organic matter	Traces of.
Phosphoric acid	Traces of.
Iron	Traces of.

Substances in the water.	*Grains.*
Sulphuric acid	7·44
Chlorine	6·31
Carbonic acid (after boiling)	5 84
Silicia	0·50
Sodium combined with chlorine	4·22
Soda combined with sulphuric and carbonic acid	10·87
Lime	1·96
Magnesia	0 71
Organic matter	Traces of.
Phosphoric acid	Traces of.
Iron	Traces of.

In one gallon of New Swindon water there were—

	Grains in a gallon.
Chloride of magnesium (bittern)	·464
Sulphate of " (Epsom salts)	·048
Sulphate of soda (glauber salts)	5·744
Chloride of sodium (common salt)	2·736
Carbonate of lime (chalk)	12·16
Sulphate of lime (gypsum)	10·4
Organic matter (vegetable extract)	·608
	32·16

This water averages 20 grains of hardness, as it is called, which is more than the average of the London or Bristol spring waters, which run from 12 to 16 grains. By boiling the water is reduced to 12 grains hardness.

These analyses of water indicate that locality has much to do with its comparative purity, and that in London, the shallow wells above the chalk, or about 200 to 220 feet deep, are more impure than those deep wells which draw their supplies below the chalk, or about 400 to 426 feet deep, as at the Royal Mint.

By knowing the particular impurities in any particular water, the practical engineer can decide with confidence whether it is or is not desirable to employ any chemical agent, such as oxalic acid, carbonate of potash, or soda, to precipitate, or nitric, muriatic, or acetic acid, to hold in solution and pass through with the steam some one of these impurities.

If only one agent, such as muriate of ammonia, be used, which thus holds in solution one of the impurities, say carbonate of lime, whilst the others, such as the sulphate of lime, are deposited by boiling; then it may even be more than doubtful if there be any present gain, and scarcely doubtful as to future injury to the rubbing surfaces and to the boiler itself, whilst the presence of any foreign body in the steam necessarily impairs its efficacy.

The effect of acids on iron is well known, and notwithstanding their dilution when used in boilers, they still appear to exercise injurious effects on particular makes of iron. In some locomotive boilers where muriate of ammonia has been employed, the internal surface of the part below the tubes was so deeply oxydized in numerous spots as to render it necessary to replace the plates to prevent accidents. In other boilers this effect is not so apparent. This difference is probably owing to the quality of the iron, or to the greater or lesser quantity of oxygen or other bodies it contains, having more or less affinity for acids, as both boilers were supplied with the same water. Similar results are observed from the action of the fire upon copper fire boxes, where one fire box will last much longer than another. The advocates of these chemical agents deny their injurious action, but the accumulating evidence of observed destruction of tender tanks and boilers is a strong presumption that they cannot be used safely with every sort of iron, even if their employment were otherwise beneficial. Dr. Davies's analysis of locomotive deposits shows that they contain carbonate and sulphate of lime with a little magnesia, protoxide of iron, silicia and carbonaceous matter; and one about one tenth of an inch thick had formed during a run of 436 miles, and the consumption of 10,900 gallons of water.

*Hard and Soft Water for Domestic Use.**

Since water for domestic use is still more important to the public generally, the following remarks on its household properties will usefully conclude this chapter.

"The popular expressions *hard* and *soft* water really give little information concerning the wholesomeness or character of a particular water, and its adaptation for drinking or culinary or even washing purposes. Water may be 'soft,' free from organic impurity, but, owing to the presence of a large quantity of mineral matter, be quite unfitted for drinking, cooking, or even for washing. To give a practical illustration: the water supplying the Trafalgar Square fountains, and which is lifted from a well sunk into the chalk formation beneath the London clay, the bottom of which is about 350 feet below the level of the sea, is a 'soft' water about $5\frac{1}{2}^{\circ}$ of hardness; but this water contains, according to the analysis of Mr. Brande and the Royal College of Chemistry, from 66 to 79 grains of mineral matter per gallon, from 60 to 72 grains of which are common salt and soda: water of this description is unfitted for drinking or making tea, and some other culinary operations, because the soda contained in it, when habitually used, acts medicinally on the kidneys; and

* S. C. Homersham, on the Supply of Water to the Metropolis. J. Weale, London.

it is unfitted for washing, because the effect of soda, if used for washing clothes, tends to discolour white cotton, flannel, or linen, and to spoil the colours of certain prints; it is also unfitted for warm baths, because the soda is apt to form a soap with the oily matter which exudes from the pores of the skin, and therefore causes it to become rough and chap.

"On the other hand, water may be 'soft' from the almost entire absence of mineral matter in solution; water of this description, from only 1° to 2° of hardness, may be found in streams fed from the rain falling upon the primitive geological formations. I have had water analyzed that was collected from streams fed by the rain falling upon the millstone-grit formation containing only $2\frac{1}{2}$ grains of mineral matter per gallon, and only $1\frac{1}{10}$th degree of hardness, and yet the use of this water for most purposes is avoided by the inhabitants living near these streams, because a large portion of the ground draining into them is covered with peat, which, being taken into solution, and especially in summer weather, so completely contaminates the water with organic matter, that it is unfitted for drinking; for, when so used, it produces sickness and diarrhœa. These streams, especially after heavy rains in the summer time, are discoloured with peat, and if used for washing, stain the coarsest linen and dim the bright colours of printed goods. This water is also bad for making tea, and spring water of a somewhat *harder* character (about 4° of hardness) is used in preference for this purpose; because, as the inhabitants express it, such very soft water draws out the wood of the tea, and spoils the flavour.

"It may be noted that M. Soyer states as the result of his experiment upon tea-making, that 'the softest or distilled water had an extraordinary power in obtaining a quick extract; *the result showed perhaps too high a power, for it draws out the woody flavour.*' It is some years since my attention was first practically drawn to the fact that water might be too soft for the making of tea, and M. Soyer's evidence accords with popular experience in this respect.

"It may not be out of place to mention here that carbonate of soda, when added to a solution of tea, deepens the colour of the tea, without either improving the flavour or the strength; any one may prove this by pouring out a cup of tea and separating it from the grouts; if a small quantity of carbonate of soda be added to such a solution, the colour will be sensibly deepened, although it is quite evident that the strength of the tea is no greater after the addition of the soda than before. This fact may account for M. Soyer stating, that the water procured from the deep well of the Reform Club and Trafalgar Square fountains (both of which waters contain a quantity of carbonate of soda) ranks number one for tea-making; M. Soyer being doubtless misled by the *colour* of the infusion. His taste, being habituated to a water containing soda, would not be offended by the taste of this alkali.

"As we see, then, water may be 'soft' and free from organic matter, and yet, from the presence of a large quantity of alkaline salts, be unfitted for nearly all domestic uses. Water may also be 'soft' from the almost entire absence of salts, and yet from its high extractive power be unfitted for tea-making; while such water, especially in summer, when collected from the drainage of land covered with peat, or even vegetation of any kind, takes greedily in solution organic matter, which renders it unwholesome for drinking, and when discoloured with peat, quite unfitted for washing purposes.

"It is only when 'soft' water is free from alkaline salts, and devoid of organic matter in solution, that it can be considered as fitted for domestic purposes. Spring water issuing from the millstone grit, and other primitive formations, is often of this character; but the soft surface water collected in reservoirs, and used to supply Preston, Bury, Ashton, and other towns in Lancashire, is not good drinking water, owing to its containing, in the summer, organic matter; and it is a pity, that when Dr. Sutherland was directed to make his 'local investigations' in Scotland and Lancashire, he was not instructed to inquire particularly into the amount of organic matter contained during autumn and summer weather in the 'soft' water collected in reservoirs for the use of town populations; had he done so, he would have discovered, what is well known to all practically acquainted with the subject, that the great bulk of such waters, at these seasons, is impregnated with organic impurities.

"The term *hard* water is equally indefinite as *soft* water. 'Hard' water may be 'hard' from holding in solution (as explained in the body of the Report) a certain amount of either lime salts or magnesian salts; and the character of a lime salt or magnesian salt again varies according as it may be combined with carbonic acid on the one hand, sulphuric acid, nitric acid, or any other acid, on the other hand. The quality and adaptation of a 'hard' water for domestic purposes is very different, according as it may be 'hard' from the presence of magnesia or lime, or of both these salts; so that it is only by knowing the amount and character of the mineral matter from which a water derives its 'hardness' that its wholesomeness or unwholesomeness, and its adaptation for domestic purposes, can be predicted.

"Again: 'hard' water may be contaminated, especially when warm, with excremental or organic matter in solution, although it is not so rapidly poisoned with these impurities as 'soft' water when free from alkaline salts."

CHAPTER II.

HEAT.

This widely-diffused body has led to much learned discussion on its nature, without arriving at any definite result. Its effects are apparent to all, but its nature is yet conjectural.

Its measurable quantity is comparatively ascertained by an instrument called a *thermometer*, and the quantity indicated on a scale of equal parts is designated its *temperature*.

The general effect of heat upon all bodies is to increase their bulk in some unascertained ratio to their density and molecular formation, excepting those bodies which diminish in volume, by heat evaporating the water they contain, such as newly-cut peat or clay.

Solids expand least, fluids next, and gases most by equal increments of heat. As compared with each other, neither solids nor fluids of the same class expand equally, a fact which has hitherto prevented any general law being defined for the rate of expansion of each class. Usually, though not always, the lighter bodies expand more than the heavier ones, as alcohol expands more than water, and water more than mercury.

Platinum, gold, silver, and zinc follow the general law, but copper, iron, and marble form exceptions.

The following Table, No. 5, shows the lineal expansion of solid bodies, from 32° to 212° by different experimenters.

In such delicate experiments uniformity of results is not to be expected, yet the averages may be taken as given in Table No. 6.

Table No. 5.

LINEAR EXPANSION OF SOLIDS AT 212° TAKING THE LENGTH OF THE BAR. AT 32° FAHR. AS 1 FOOT.

Name.	Experimenter.	Length at 212°. Feet.
Glass tube	Smeaton	1·00083333
Ditto	Roy	1·00077615
Ditto	Deluc's mean	1·00082800
Ditto	Dulong and Petit	1·00086130
Ditto	Lavoisier and Laplace	1·00081166
Plate glass	Ditto	1·00089089
Ditto crown glass	Ditto	1·00087572
Ditto	Ditto	1·00089760
Ditto	Ditto	1·00091751

Name.	Expermentor.	Length at 212°. Feet.
Glass rod	Roy	1·00080787
Platina purified	Roy, as glass	1·000857
Platina	Borda	1·00085655
Ditto	Dulong and Petit	1·00088420
Ditto.	Troughton	1·00099180
Ditto and glass	Berthoud	1·00110000
Palladium	Wollaston	1·00100000
Antimony	Smeaton	1·00108300
Cast-iron prism	Roy	1·00110940
Cast-iron	Lavoisier, by Dr. Young	1·00111111
Steel	Troughton	1·00118990
Ditto rod	Roy	1·00114470
Blistered steel	Phil. Trans. 1795, p. 428	1·00112500
Ditto	Smeaton	1·00107875
Steel not tempered	Lavoisier and Laplace	1·00107956
Ditto	Ditto	1·00107956
Ditto tempered yellow	Ditto	1·00136900
Ditto	Ditto	1·00138600
Ditto at a higher rate	Ditto	1·00123956
Steel	Troughton	1·00118980
Hard steel	Smeaton	1·00122500
Annealed steel	Musschenbröck	1·00122000
Tempered steel	Ditto	1·00137000
Iron	Borda	1·00115600
Ditto	Smeaton	1·00125800
Soft iron forged	Lavoisier and Laplace	1·00122045
Round iron, wire drawn	Ditto	1·00123504
Iron wire	Troughton	1·00144010
Iron	Dulong and Petit	1·00118203
Bismuth	Smeaton	1·00139200
Annealed gold	Musschenbröck	1·00146000
Gold	Ellicot, by comparison	1·00150000
Ditto, procured by parting	Lavoisier and Laplace	1·00146606
Ditto, Paris standard	Ditto	1·00155155
Ditto, pure hammered	Ditto	1·001514
Ditto, ditto, annealed	Ditto	1·00151361
Copper	Musschenbröck	1·00191080
Ditto	Lavoisier and Laplace	1·00172244
Ditto	Ditto	1·00171222
Ditto	Troughton	1·00191880
Ditto	Dulong and Petit	1·00171821
Brass	Borda	1·00178300
Ditto	Lavoisier and Laplace	1·00186671
Ditto	Ditto	1·00188971
Brass scale, supposed from Hamburgh	Roy	1·00185540
Cast brass	Smeaton	1·00187500

Name.	Experimenter.	Length at 212°. Feet.
English plate brass, in form	Roy	1·00189280
Ditto, in a trough form	Ditto	1·00189490
Brass	Troughton	1·00191880
Ditto wire	Smeaton	1·00193000
Brass	Musschenbröck	1·00216000
Copper 8, tin 1	Smeaton	1·00181700
Silver	Herbert	1·00189000
Ditto	Ellicot, by comparison	1·00210000
Silver	Musschenbröck	1·00212000
Ditto of cupel	Lavoisier and Laplace	1·00190971
Ditto, Paris standard	Ditto	1·00190868
Silver	Troughton	1·00208260
Brass 16, tin 1	Smeaton	1·00190800
Speculum metal	Ditto	1·00193340
Spelter solder; brass 2, zinc 1	Ditto	1·00205800
Malacca tin	Lavoisier and Laplace	1·00193765
Tin from Falmouth	Ditto	1·00217298
Fine pewter	Smeaton	1·00228300
Grain tin	Ditto	1·00248300
Tin	Musschenbrock	1·00284000
Soft solder; lead 2, tin 1	Smeaton	1·00250800
Zinc 8, tin 1, a little hammered	Ditto	1·00269200
Lead	Lavoisier and Laplace	1·00284836
Ditto	Smeaton	1·00286700
Zinc	Ditto	1·00294200
Ditto, hammered out half-inch per foot	Ditto	1·00301100
Glass, from 32° to 212°	Dulong and Petit	1·00086130
Ditto, from 212° to 392°	Ditto	1·00091827
Ditto, from 392° to 572°	Ditto	1·000101114

The linear expansion multiplied by three gives the *total* expansion nearly. Thus for iron it would be 1 in 271, and for lead 1 in 117 to be considered in buildings; or, as in the instance of Bow Church spire, it may endanger the structure. The contracting power of expanded iron is usefully employed in various ways, and was the means used to draw the walls of the Museum of Arts in Paris from an inclining to a vertical position. The strain on many parts of locomotive engines from the unequal temperature and expansion of copper, brass, and iron will be readily calculated by the following averages which divided by three give the *ratio* of increased bulk.

Table No. 6.

AVERAGES OF A FEW OF THE PRINCIPAL SOLIDS.

Averages of the Linear Expansion of Metals from 32° to 212°.

Name.	Increased length at 212°.		Name.	Increased length at 212°.	
Zinc sheet,	1 part in . .	340	Iron,	1 part in . .	812
Zinc, cast,	,, . .	322	Antimony	,, . .	923
Lead	,, . .	351	Palladium,	,, . .	1000
Tin, pure,	,, . .	403	Platinum,	,, . .	1167
Tin, impure,	,, . .	516	Glass,	,, . .	1160
Silver,	,, . .	524	Marble,	,, . .	2833
Copper,	,, . .	581	Iron, soft	,, . .	818
Brass,	,, . .	584	Iron, cast	,, . .	900
Gold,	,, . .	682	Steel, tempered	,, . .	806
Bismuth,	,, . .	719	Steel	,, . .	926

Sheet zinc as employed on roofs of buildings or for covering locomotive boilers, exhibits in a marked manner the effects of expansion, in causing it to "blister and crack," which renders it an inferior article for such purposes.

The following tables will further illustrate this property of heat.

Table No. 7.

EXPANSION OF FLUIDS BY THE ADDITION OF 180° OF HEAT, OR AT 212° TAKING THE BULK OR VOLUME AT 32° AS 1 CUBIC FOOT.

Name.				Cub. ft.		Cub. ft.
Air . . .	1 part in	2·73	or	1000	become	1366
Alcohol . .	1	9		1000		1110
Nitric acid (s. g. 1·4) .	1	9		1000		1111
Fixed oils . .	1	12		1000		1083
Turpentine . .	1	14		1000		1071
Sulphuric ether . .	1	14		1000		1071
Sulphuric acid (s. g. 1·85)	1	17		1000		1058
Muriatic acid (s. g. 1·137)	1	17		1000		1058
Salt water . .	1	20		1000		1050
Water	1	22		1000		1045
Mercury . .	1	55		1000		1018
Mercury, apparent in glass	1	64		1000		1015.

Table No. 8.

COMPARATIVE EXPANSION OF WATER AND AIR BY HEAT.

Deg. Fah.	Water.	Air.	Deg. Fah	Water	Air.
12	1·00236		122	1·01116	1·198
22	1·00092		132	1·01367	1·219
32	1·00022	1·000	142	1·01638	1·239
40	• 1·00000	1·021	152	1·01934	1·259
52	1·00021	1·047	162	1·02245	1·279
62	1 00083	1·071	172	1·02575	1·299
72	1·00180	1·093	182	1·02916	1·319
82	1·00312	1·114	192	1·03265	1·338
92	1·00477	1·136	202	1·03634	1·357
102	1·00672	1·156	212	1·04012	1·376
112	1·00880	1·177			

Thermometers.

The general law of expansion by heat, as shown in these tables, suggested the mode of measuring the heat in any body by comparison with the rate of expansion in a given body. The medical advantages of determining the comparative temperatures of the body and the air in sick chambers, led Sanctori, an Italian physician, to construct an air thermometer in 1590, to aid him in his practice, being the earliest we have an account of. In 1655 alcohol was substituted for air, and although both air and spirit thermometers are still employed in scientific investigations at very high or very low temperatures, mercurial thermometers are generally used.

The qualities of mercury for the thermometer are its fluidity through a range of nearly 700° under atmospheric pressure, and about 630° in the vacuum of a thermometer, where its fluidity extends below the freezing point of water, about 40°, and above its boiling point, 378°. It is not, however, a perfect instrument, as its rate of expansion increases for equal increments of heat at high temperatures, and it also deteriorates by use, which renders it necessary to check its indications for minute investigations by the more uniform expansion of the air thermometer.

Quicksilver was its original name, but the alchemists of old fancied that the metals had some mysterious relation to the heavenly bodies. Thus they called :

Gold, the Sun ; Silver, Moon ; Quicksilver, Mercury ; Copper, Venus ; Iron, Mars ; Tin, Jupiter ; Lead, Saturn.

If they were unable to find the *elixir vitæ*, or the philosopher's stone, yet amid their visionary schemes, science is indebted to their researches, and quicksilver retains the name they gave it in ordinary use. As a metal, mercury has a beautiful silvery appearance, and both in art and in medicine it is extensively employed. The following are a few of its exponents; like other instances of the same kind experimentalists do not all give the same exponents.

Its specific gravity when solid at 40° below zero, is 13·64 times the weight of water of an equal bulk. At 60° it is 13·58; at 212° it is 13·37, and at 590° it begins to boil in the thermometer, but not until 660° in the open air.

Mercurial Thermometer.

This instrument is usually made with a slender glass tube of equal bore, having an enlarged end, which, with a part of the tube, is filled with mercury. It is then made to boil, that the expansion of the mercury may expel the air from the unfilled part of the tube, when the open end is fused together to prevent the admission of any more air. Thus enclosed from the pressure of the atmosphere, the mercury ascends by expansion as heat is communicated to it, or descends by contraction as heat is withdrawn from it. To give two fixed points in a scale of parts for the rise and fall of mercury, Dr. Hook suggested, and Sir I. Newton adopted the freezing and boiling points of water for that purpose, which is still acted upon.

These points are obtained by immersing the prepared tube containing mercury, alternately in freezing and boiling water, and marking the level at which the mercury becomes stationary in each trial. The distance between these points is then divided into a number of equal parts, and the scale extended as required. In this country thermometers are understood to be so adjusted, when the pressure of the air supports 30 inches of mercury.

Although philosophers have agreed on the fixed points of the thermometric scale, it is greatly to be regretted that they have not equally agreed on its division into equal parts, and not complicated research by a variety of scales. The distance between the freezing and boiling points is by Fahrenheit divided into 180 parts, by De Lisle into 150 parts, by Celsius into 100 parts, and by Reaumur into 80 parts, all in use in different parts of Europe. Diagrams, Nos. 4, 5, 6, 7, will show the relation these scales bear to each other.

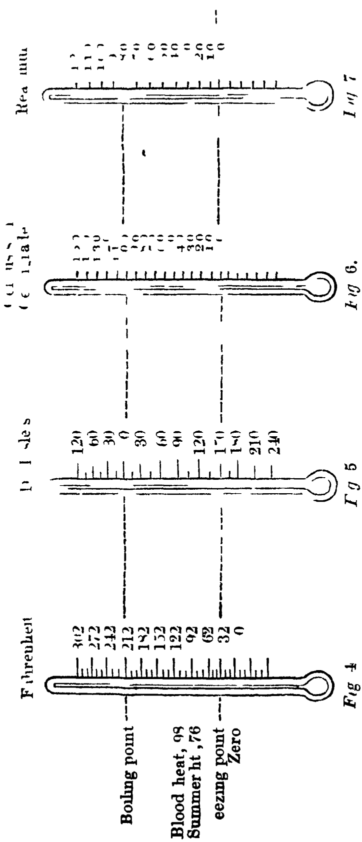


Fig. 4. $1 = \frac{5}{9}$ of 1 of Cent., or $= \frac{4}{9}$ of 1 of Reaum.; or $= \frac{1}{6}$ of 1 of De Lisle's.
Fig. 5. $1 = 1\frac{1}{3}$ of 1 of Fah.; or $= \frac{10}{15}$ of 1 of Cent.; or $= \frac{8}{15}$ of 1 of Reaum.
Fig. 6. $1 = 1\frac{1}{2}$ of 1 of De Lisle's; or $= \frac{4}{5}$ of 1 of Reaum.; or $= 1\frac{4}{5}$ of 1 of Fah
Fig. 7. $1 = 1\frac{1}{5}$ of 1 of Cent.; $1 = 2\frac{1}{4}$ of 1 of Fah., $1 = 1\frac{7}{8}$ of 1 of De Lisle's.

Comparatively, therefore, the preceding thermometers stand thus :—

	Fahr.		De Lisle.		Celsius or Cent.		Reaum.
Boiling	212		0		100		80
Freezing	32		150		0		0
No. of equal parts =	180		150		100		80
Ratio of parts =	9	=	7·5	=	5	=	4

or thus :—

1° of Fahr.	$= \frac{5}{6}$ of 1 of De Lisle's or	Fahr.	$\times \frac{5}{6}$ = De Lisle's.
1 ,,	$= \frac{5}{9}$ of 1 of Cent.	,,	$\times \frac{5}{9}$ = Cent.
1 ,,	$= \frac{4}{9}$ of 1 of Reaum.	,,	$\times \frac{4}{9}$ = Reaum.
1° of De Lisle's	$= 1\frac{1}{5}$ of 1 of Fahr. or	De Lisle's	$\times \frac{6}{5}$ = Fahr.
1 ,,	$= \frac{10}{15}$ of 1 of Cent.	,,	$\times \frac{10}{15}$ = Cent.
1 ,,	$= \frac{8}{15}$ of 1 of Reaum.	,,	$\times \frac{8}{15}$ = Reaum.
1° of Cent.	$= 1\frac{4}{5}$ of 1 of Fahr. or	Cent.	$\times \frac{9}{5}$ = Fahr.
1 ,,	$= 1\frac{1}{2}$ of 1 of De Lisle's	,,	$\times \frac{3}{2}$ = De Lisle's.
1 ,,	$= \frac{4}{5}$ of 1 of Reaum.	,,	$\times \frac{4}{5}$ = Reaum.
1° of Reaum.	$= 2\frac{1}{4}$ of 1 of Fahr. or	Reaum.	$\times \frac{9}{4}$ = Fahr.
1 ,,	$= 1\frac{7}{8}$ of 1 of De Lisle's	,,	$\times \frac{15}{8}$ = De Lisle's.
1 ,,	$= 1\frac{1}{5}$ of 1 of Cent.	,,	$\times \frac{6}{5}$ = Cent.

The multipliers are thus used—

$$180 \text{ Fahr.} \times \frac{5}{6} = \frac{180 \times 5}{6} = 150^\circ \text{ De Lisle's.}$$

$$150 \text{ DeLisle's} \times \frac{6}{5} \text{ or } 1{\cdot}2 = \frac{150 \times 6}{5} = 180^\circ \text{ Fahr.}$$

$$\text{or } 150 \times 1{\cdot}2 = 180^\circ \text{ Fahr.}$$

$$80 \text{ Reaum.} \times \frac{15}{8} = \frac{80 \times 15}{8} = 150^\circ \text{ De Lisle's.}$$

$$180 \text{ Fahr.} \times \frac{5}{9} = \frac{180 \times 5}{9} = 100 \text{ Cent.}$$

$$100 \text{ Cent.} \times \frac{9}{5} \text{ or } 1{\cdot}8 = \frac{100 \times 9}{5} = 180 \text{ Fah.}$$

$$\text{or } 100 \times 1{\cdot}8 = 180^\circ \text{ Fahr.}$$

Whilst by these multipliers we are enabled to convert the degrees of one into those of the other, yet, as their notation is different, it requires attention to subtract the 32° of Fahrenheit from the reading off other scales, before the multiplier is used. Thus, Fahr. $212° - 32 \times \frac{5}{9} = 100°$ Cent.

From the freezing point to zero, it requires the number for a Fahrenheit scale to be subtracted from 32°. Thus,

$$\text{Fahr. } 14 \text{, then } 32 - 14 \times \tfrac{5}{9} = 10 \text{ Cent.}$$

Below zero, it requires the 32° to be added. Thus,

$$\text{Fahr.} - 58° + 32° \times \tfrac{5}{9} - 50° \text{ Cent.}$$

and in like manner with Reaumur's scale.

De Lisle's notation commencing at 212° Fahrenheit's, 100° Cent. and 80° Reaumur, requires the quantity found by the multipliers to be deducted from 150° for the reading on his scale: thus 206 Fah. = 5 De Lisle's, for

$$\frac{206 - 32 \times 5}{6} = 115 \text{ and } 150 - 115 = 5° \text{ De Lisle's.}$$

For it will be observed they differ in their zero or starting point as well as in their scale of parts. In 1709 Fahrenheit having artificially obtained a degree of cold 32° below the freezing point of water, imagined it to be the greatest possible cold, and fixed it as the starting point for his scale used in this country. Recent experiments have, however, gone as low as 148° below Fahrenheit's zero, and Dulong and Petit regard the point where heat is not to be found at all, as undefinable. As cold is only the expression for the comparative absence of heat, the greatest degree of cold it appears is not determinable. In 1730 Reaumur fixed his zero at the freezing point, so also did Celsius, whose scale is used in France, but in 1733, De Lisle fixed his zero at the boiling point. Thus, in reading off De Lisle's own scale, say at 80°, it would be 150° (the range between boiling and freezing) − 80 = 70° above the freezing point.

From this brief explanation of the principal thermometers it will be obvious that one uniform scale, such as the centigrade or decimal scale, would be far preferable for both scientific and practical purposes, than a constant recourse to calculation to ascertain the comparative temperatures.

In this respect the following table will be found useful.

Table No. 9.

COMPARATIVE TEMPERATURES OF FAHR., DE LISLE, CELSIUS, REAUM., FROM 600° FAHR. TO FREEZING POINT OF MERCURY.

Fahr.	De Lisle.	Celsius.	Reaum.	Fahr.	De Lisle.	Celsius.	Reaum.
600	323·3	315·5	252·4	338	105·	170·	136·
580	306·6	301·4	213·5	337	104·1	169·4	135·5
560	290·6	293·3	234·6	336	103·3	168·8	134·1
540	273·3	282·2	225·7	335	102·5	168·3	134·6
520	256·6	271·1	216·8	334	101·6	167.7	134·2
500	210·	260·	208·	333	100·8	167·2	133·7
490	231·6	254·4	203·5	332	100·	166·6	133·3
480	223·3	218·8	199·1	331	99·1	166·1	132·8
470	215·	213·3	194·6	330	98·3	165·5	132·4
460	206·6	237·7	199·2	329	97·5	165·	132·
450	198·3	232·2	185·8	328	96·6	164·4	131·5
440	190·	226·6	181·4	327	95·8	163·8	131·1
430	181·6	221·1	176·8	326	95·	163·3	130·6
420	173·3	215·5	172·4	325	94·1	162·7	130·2
410	165·	210·	168·	324	93·3	162·2	129·7
400	156·6	204·4	163·5	323	92·5	161·6	129·3
395	152·4	201·6	161·3	322	91·6	161·1	128·8
390	148·3	198·8	159·1	321	90·8	160·5	128·4
385	144·1	196·1	156·9	320	90·	160·	128·
380	140·	193·2	154·6	319	89·1	159·4	127·5
375	135·8	190·5	152·4	318	88·3	158·8	127·1
370	131·6	187·7	150·2	317	87·5	158·3	126·6
365	127·5	185·	148·	316	86·6	157·7	126·2
360	123·3	182·2	145·8	315	85·8	157·2	125·7
355	119·16	179·4	143·5	314	85·	156·6	125·3
350	115·	176·6	141·3	313	84·1	156·1	126·8
345	110·83	174·	139·	312	83·3	155·5	124·4
340	106·6	171·1	136·8	311	82·5	155·	124·
339	105·8	170·5	136·4	310	81·6	154·4	123·5

Fahr.	De Lisle.	Celsius.	Reaum.	Fahr.	De Lisle.	Celsius	Reaum.
309	80·8	153·8	123·1	265	44·1	129·4	103·5
308	80·	153·3	122·6	264	43·3	128·8	103·1
307	79·1	152·7	122·2	263	42·5	128·3	102·6
306	78·3	152·2	121·7	262	41·6	127·7	102·2
305	77·5	151·6	121·3	261	40·8	127·1	101·7
304	76·6	151·1	120·8	260	40·	126·6	101·3
303	75·8	150·5	120·4	259	39·1	126·1	100·8
302	75·	150·	120·	258	38·3	125·5	100·4
301	74·1	149·4	119·5	257	37·5	125·	100·
300	73·3	148·8	119·1	256	36·6	124·4	99·5
299	72·5	148·3	118·6	255	35·8	123·8	99·1
298	71·6	147·7	118·2	254	35·	123·3	98·6
297	70·8	147·2	117·7	253	34·1	122·7	98·2
296	70·	146·6	117·3	252	33·3	122·2	97·7
295	69·1	146·1	116·8	251	32·5	121·6	97·3
294	68·3	145·5	116·4	250	31·6	121·1	96·8
293	67.5	145·	116·	249	30·8	120·5	96·4
292	66·6	144·4	115·5	248	30·	120·	96·
291	65·8	143·8	115·1	247	29·1	119·4	95·5
290	65·	143·3	114·6	246	28·3	118·8	95·1
289	64·1	142·7	114·2	245	27·5	118·3	94·6
288	63·3	142·2	113·7	244	26·6	117·7	94·2
287	62·5	141·6	113·3	243	25·8	117·2	93·7
286	61·6	141·1	112·8	242	25·	116·6	93·3
285	60·8	140·5	112·4	241	24·1	116·1	92·8
284	60·	140·	112·	240	23·3	115·5	92·4
283	59·1	140·4	111·5	239	22·5	115·	92·
282	58·3	139·8	111·1	238	21·6	114·4	91·5
281	57·5	139·3	110·6	237	20·8	113·8	91·1
280	56·6	138·7	110·2	236	20·0	113·3	90·6
279	55·8	138·2	109·7	235	19·1	112·7	90·2
278	55·	137·6	109·3	234	18·3	112·2	89·7
277	54·1	136·1	108·8	233	17·4	111·6	89·3
276	53·3	135·5	108·4	232	16·6	111·1	88·8
275	52·5	135·	108·	231	15·8	110·5	88·4
274	51·6	134·4	107·5	230	15·	110·	88·
273	50·8	133·8	107·1	229	14·1	109·4	87·5
272	50·	133·3	106·6	228	13·3	108·8	87·1
271	49·1	132·7	106·2	227	12·5	108·3	86·6
270	48·3	132·2	105·7	226	11·6	107·7	86·2
269	47·5	131·6	105·3	225	10·8	107·2	85·7
268	46·6	131·1	104·8	224	10·	106·6	85·3
267	45·8	130·5	104·4	223	9·1	106·1	84·8
266	45·	130·	104·	222	8·3	105·5	84·4

Fahr.	De Lisle.	Celsius.	Reaum.	Fahr.	De Lisle.	Celsius.	Reaum.
221	7·5	105·	84·	177	29·1	80·5	64·4
220	6·6	104·4	83.5	176	30·	80·	64·
219	5·8	103·8	83·1	175	30·8	79·4	63·5
218	5·0	103·3	82·6	174	31·6	78·8	63·1
217	4·1	102·7	82·2	173	32·5	78·3	62.6
216	3·3	102·2	81·7	172	33·3	77·7	62·2
215	2·5	101·6	81·3	171	34·1	77·2	61·7
214	1·6	101·1	80·8	170	35·	76·6	61·3
213	·8	100·5	80·4	169	35·8	76·1	60·8
212	zero	100·	80·	168	36·6	75·5	60·4
211	·8	99·4	79·5	167	37·5	75·	60·
210	1·6	98·8	79·1	166	38·3	74·4	59·5
209	2·5	98·3	78·6	165	39·1	73·8	59·1
208	3·3	97·7	78·2	164	40·	73·3	58·6
207	4·1	97·2	77·7	163	40·8	72·7	58·2
206	5·0	96·6	77·3	162	41·6	72·2	57·7
205	5·8	96·1	76·8	161	42·5	71·6	57·3
204	6·6	96·5	76·4	160	43·3	71·1	56·8
203	7·5	95·0	76·	159	44·1	70·5	56·4
202	8·3	94·4	75·5	158	45·	70·	56·
201	9·1	93·8	75·1	157	45·8	69·4	55·5
200	10·	93·3	74·6	156	46·6	68·8	55·1
199	10·8	92·7	74·2	155	47·5	68·3	54·6
198	11·6	92·2	73·7	154	48·3	67·7	54·2
197	12·5	91·6	73·3	153	49·1	67·2	53·7
196	13·3	91·0	72·8	152	50·	66·6	53·3
195	14·1	90·5	72·4	151	50·8	66·1	52·8
194	15·	90·	72·	150	51·6	65·5	52·4
193	15·8	89·4	71·5	149	52·5	65·	52·
192	16·6	88·8	71·1	148	53·3	64·4	51·5
191	17·5	88·3	70·6	147	54·1	63·8	51·1
190	18·3	87·7	70·2	146	55·	63·3	50·6
189	19·1	87·2	69·7	145	55·8	62·7	50·2
188	20·	86·6	69·3	144	56·6	62·2	49·7
187	20·8	86·1	68·8	143	57·5	61·6	49·3
186	21·6	85·5	68·4	142	58·3	61·1	48·8
185	22·5	85·	68·	141	59·1	60·5	48·4
184	23·3	84·4	67·5	140	60·	60·	48·
183	24·1	83·8	67·1	139	60·8	59·4	47·5
182	25·	83·3	66·6	138	61·6	58·8	47·1
181	25·8	82·7	66·2	137	62·5	58·3	46·6
180	26·6	82·2	65·7	136	63·3	57·7	46·2
179	27·5	81·6	65·3	135	64·1	57·2	45·7
178	28·3	81·1	64·8	134	65·	56·6	45·3

Fahr.	De Lisle.	Celsius.	Reaum.	Fahr.	De Lisle.	Celsius.	Reaum.
133	65·8	56·1	44·9	89	102·5	31·6	25·3
132	66·6	55·5	44·4	88	133·3	31·1	24·8
131	67·5	55·	44·	87	104·1	30·5	24·4
130	68·3	54·4	43·5	86	105·	30·	24·
129	69·1	53·8	43·1	85	105·8	29·4	23·5
128	70·	53·3	42·6	84	106·6	28·8	23·1
127	70·8	52·7	42·2	83	107·5	28·3	22·6
126	71·6	52·2	41·7	82	108·3	27·7	22·2
125	72·5	51·6	41·3	81	109·1	27·2	21·7
124	73·8	51·1	40·8	80	110·	26·6	21·3
123	74·1	50.5	40·4	79	110·8	26·1	20·8
122	75·	50·	40·	78	111·6	25·5	20·4
121	75·8	49·4	39·5	77	112·5	25·	20·
120	76·6	48·8	39·1	76	113·3	24·4	19·5
119	77·5	48·3	38·6	75	114·1	23·8	19·1
118	78·3	47·7	38·2	74	115·	23·3	18·6
117	79·1	47·2	37·7	73	115·8	22·7	18·2
116	80·	46·6	37·3	72	116·6	22·2	17·7
115	80·8	46·1	36·8	71	117·5	21·6	17·3
114	81·6	45·5	36·4	70	118·3	21·1	16·8
113	82·5	45·	36·	69	119·1	20·5	16·4
112	83·3	44·4	35·5	68	120·	20·	16·
111	84·1	43·8	35·1	67	120·8	19·4	15·5
110	85·	43·3	34·6	66	121·6	18·8	15·1
109	85·8	72·7	34·2	65	122·5	18·3	14·6
108	86·6	42·2	33·7	64	123·3	17·7	14·2
107	87·3	41·6	33·3	63	124·1	17·2	13·7
106	88·3	41·1	32·8	62	125·0	16·6	13·3
105	89·1	40·5	32·4	61	125·8	16·1	12·8
104	90·	40·	32·	60	126·6	15·5	12·4
103	90·8	39·4	31·5	59	127·5	15·	12·
102	91·6	38·8	31·1	58	128·3	14·4	11·5
101	92·5	38·3	30·6	57	129·1	13·8	11·1
100	93·3	37·7	30·2	56	130·	13·3	10·6
99	94·1	37·2	29·7	55	130·8	12·7	10·2
98	95·	36·6	29·3	54	131·6	12·2	9·7
97	95·8	36·1	28·8	53	132·5	11·6	9·3
96	96·6	35·5	28·4	52	133·3	11·1	8·8
95	97·5	35·	28·	51	134·1	10·5	8·4
94	98·3	34·	27·5	50	135·	10·	8·
93	99·1	33·4	27·1	49	135·8	9·4	7·5
92	100·	33·8	26·6	48	136·6	8·8	7·1
91	100·8	32·7	26·2	47	137·5	8·3	6·6
90	101·6	32·2	25·7	46	138·3	7·7	6·2

Fahr.	De Lisle.	Celsius.	Reaum.	Fahr.	De Lisle.	Celsius.	Reaum.
45	139·1	7·2	5·7	1	175·8	17·2	13·7
44	140·	6·6	5·3	zero	176·6	17·7	14·2
43	143·8	6·1	4·8	1	175·8	18·3	14·6
42	141·6	5·5	4·4	2	178·3	18·8	15·1
41	142·5	5·	4·	3	179·1	19·4	15·5
40	143·3	4·4	3·5	4	180·	20·	16·
39	144·1	3·8	3·1	5	180·8	20·5	16·4
38	145·	3·3	2·6	6	181·6	21·1	16·8
37	145·8	2·7	2·2	7	182·5	21·6	17·3
36	146·6	2·2	1·7	8	183·3	22·2	17·7
35	147·5	1·6	1·3	9	184·1	22·7	18·2
34	148·3	1·1	0·8	10	185·	23·3	18·6
33	149·1	0·5	0·4	11	185·8	23·8	19·1
32	150·	zero	zero	12	186·6	24·4	19·5
31	150·8	0·5	0·4	13	187·5	25·	20·
30	151·6	1·1	0·8	14	188·3	25·5	20·4
29	152·5	1·6	1·3	15	189·1	26·1	20·8
28	153·3	2·2	1·7	16	190·	26·6	21·3
27	154·1	2·7	2·2	17	190·8	27·2	21·7
26	155·	3·3	2·6	18	191·6	27·7	22·2
25	155·8	3·8	3·1	19	192·5	28·3	22·6
24	156·6	4·4	3·4	20	193·3	28·8	23·1
23	157·5	5·	4·	21	194·1	29·4	23·5
22	158·3	5·5	4·4	22	195·	30·	24·
21	159·1	6·1	4·8	23	195·8	30·5	24·4
20	160·	6·6	5·3	24	196·6	31·1	24·8
19	160·8	7·2	5·7	25	197·5	31·6	25·3
18	161·6	7·7	6·2	26	198·3	32·2	25·7
17	162·5	8·3	6·6	27	199·1	32·7	26·2
16	163·3	8·8	7·1	28	200·	33·3	26·6
15	164·1	9·4	7·5	29	200·8	33·8	27·1
14	165·	10·	8·	30	201·6	34·4	27·5
13	165·8	10·5	8·4	31	202·5	35·	28·
12	166·6	11·1	8·8	32	203·3	35·5	28·4
11	167·5	11·6	9·3	33	204·1	36·1	28·8
10	168·3	12·2	9·7	34	205·	36·6	29·5
9	169·1	12·7	10·2	35	205·8	37·2	29·7
8	170·	13·3	10·6	36	206·6	37·7	30·2
7	170·8	13·8	11·1	37	207·5	38·3	30·6
6	171·6	14·4	11·5	38	208·3	38·8	31·1
5	172·5	15·	12·	39	209·1	39·4	31·5
4	173·3	15·5	12·4	40	210·	40·	32·
3	174·1	16·1	12·8	41	210·9	40·5	32·4
2	175·	16·6	13·3	42	211·6	41·1	32·9

The following table exhibits a few of the effects of heat, which may be instructive.

TABLE No. 10.

EFFECTS OF HEAT.

		Fahr. below zero.	
Artificial cold produced by Thelorier		133	
Solid alcohol and carbonic acid	melts	121	
Artificial cold produced by Walker		91	
Natural cold observed by Ross		60	
,, ,, of planetary space (Fourc.)		58	
,, ,, observed by Parry		55	
,, ,, ,, at Hudson's Bay		50	
,, ,, ,, at Glasgow, 1780		23	
Liquid ammonia	melts	46	
Nitric acid (sp. gr. 1·424)	melts	46	boils 210°
Mercury	freezes	39	boils 660°

,, expands 1 in 55½ from 32 to 212, or 1·80 per cent.
,, ,, 1 in 51¼ from 212 to 392, or 1·83 ,,
,, ,, 1 in 53 from 392 to 472, or 1·88 ,,
,, ,, 1 in 64·8 in glass tubes,* or 1·54 ,,

Dulong and Petit.

Creosote	still fluid at	17	boils 397°
Oil of vitriol	freezes	13	
Bromine	melts	10	boils 117°
Water 1, alcohol 1	temp.	7	
,, 1, snow 1	temp. zero of Fah.		
,, 1, salt 3	temp.	4 above zero	
,, 78, salt 22	temp.	7	
Turpentine	freezes	14	boils 314°
Strong wine	freezes	20	

Blood, human, freezes 25; life heat, 98; fever heat, 107.

,, ,, composed of water, 78·56; colouring matter, (Hematosin and Globulin,) 11·962.

Albumen, 6·94; fatty matter, ·43; fibrin, ·356; oily matter, ·227; albumen combined with soda, ·202; extractive matter, ·192; portions of chlo-

* From the expansion of the glass tube.

ride of sodium, potassium, carbonates, phosphates and sulphates of potash and soda altogether, ·73; carbonates of lime and magnesia, phosphates of lime, magnesia and iron, and peroxide of iron, altogether, ·142; loss in analyses, ·258; total, 100.—*M. Lecance.*

Sea water (salt 1, water 29), . . . freezes 28 boils 224°
Milk freezes 30, ferments 100, yielding some alcohol.
Ordinary milk contains—

	Water,	Sugar,	Butter,	Cheese,	Salts or mucous matter,	Total,
Woman's .	87·98	6·50	3·55	1·52	·45	100
Ass's . .	91·65	6·08	0·11	1·82	·31	100
Cow's . .	87·02	4·77	3·13	4·48	·60	100

Henry Chevallier.

Water freezes 32, boils 212°, fixed thermometrical points

			measures		per cent.
Water in cooling from	212° to 189·5	contracts	18	in 2000,	or ·9
,, ,, ,, ,,	189·5 to 167	,,	16·2 in	,,	or ·81
,, ,, ,, ,,	167· to 144·5	,,	13·8 in	,,	or ·69
,, ,, ,, ,,	144·5 to 122	,,	11·5 in	,,	or ·575
,, ,, ,, ,,	122· to 99·5	,,	9·3 in	,,	or ·465
,, ,, ,, ,,	99·5 to 77	,,	7·1 in	,,	or ·355
,, ,, ,, ,,	77· to 54·5	,,	3·9 in	,,	or ·195
,, ,, ,, ,,	54·5 to 32	,,	0·2 in	,,	or ·001

Rumford.

Olive oil, freezes 36
Phosphorus burns slowly at 43, vividly at 122, boils at 554
Mean temp. of the earth's surface 50
,, of our climate . 52
Vinous fermentation begins . 59, rapid at 77
Acetous ,, . . 77, ceases at 88
Animal putrefaction from . . 66 to 135
Summer heat in this country . 75 to 80
Heat in Great Exhibition, June 26, 1851, Floor, 85, Galleries, 95.
Carbonic acid . . melts, 85
Tallow 92
Animal heat . . . 96 to 100
Spermaceti . . . melts, 112
Sulphuret of carbon . ,, 116
Wax, yellow . . ,, 142, white 155
Stearic acid (per Chandler) ,, 158—167

Alcohol	boils,	173
Sodium	melts,	190
Bismuth 2, lead 1, tin 1	,,	201 (Rose's metal)
Steam from ordinary water,	begins to form,	212
,, sea water	,,	224
Sulphur	melts,	218, boils, 570
Iodine	,,	225, boils 347, burns 363
Tin 1, Bismuth 1	,,	289
Essential oils	boil,	320
Steel (tempering) pale yellow	temp.	330, deep blue, 580
Tin 2, Lead 1 (soft solder)	melts,	360
Tin and Cadmum	,,	442
Tin 1, Lead 3 (coarse solder)	,,	480
Bismuth	,,	476 to 507
Lead	,,	594 to 612
Whale oil	boils,	630
Iron, red heat in the dark		635, in the light 980
Linseed oil		640
Nickel magnets lose their polarity		630
Zinc	melts,	680 to 773
Hydrogen	burns,	800
Charcoal	,,	802
Antimony	melts,	797, 812
Common	temp.	1141
Bronze (100 copper, 10 tin)	melts,	1652
Brass	,,	1869
Copper	,,	1996
Silver (variously stated)	,,	1832, 1873, 2233
Gold	,,	2016, 2182
,, Money (Gold 11, Copper 1)	,,	2150
Steel	,,	2372 to 2552
Cast Iron, variously stated as		2732, 2786, 3479
Air Furnace		3500

Sources of Heat.

The chief sources of heat are the Sun, the Earth, Electricity, Friction, Percussion, Compression, and Chemical Action. There is a difference between the rays of heat from the sun which passes through glass like light, whilst the rays of heat from a fire are arrested and absorbed by the glass, and only very slowly pass through it. The effect of the rays of the sun in extinguishing a common fire are also well known.

Electric heat, like common heat, is also arrested by glass, which is accordingly employed as an insulate in electric experiments.

What heat really is so much perplexes the closest investigators, that it may be submitted, as a question to be solved by electricians, whether there is a point under the ordinary or extraordinary combinations of heat and water as applied to generate steam, when electricity would be engendered and communicated to the water. If there is such a point, and electric and common heat are only different degrees of concentration of the same body, then the great difficulty regarding steam-boiler explosions would be more satisfactorily solved than has yet been done.

Heat is communicated to other bodies in three ways,

1st. By direct contact, called *Conduction.*

2nd. By right lines, called *Radiation.*

3rd. By carrying, called *Convection.*

Conduction.

When two bodies of unequal temperature are placed in contact with each other, the hotter body communicates heat to the colder body until they become of equal temperature. The rapidity of this equalization depends upon the nature of the bodies themselves, as all bodies do not conduct heat alike, and are accordingly called good or bad conductors. Wood, for instance, is so bad a conductor of heat, that if a piece of it be set on fire at one end it can be held until the flame has reached the hand without the heat having been previously conducted by the fibres of the wood itself. Glass is also a bad conductor of heat. Fluids also conduct heat very slowly, mercury excepted.

Metals are good conductors, but vary in their power of doing so, as seen in the following tabular classification of their comparative powers of conduction.

Gold . . .	1000	Tin . . .	303·9
Platina . . .	381	Lead . . .	179·6
Silver . . .	973	Marble . . .	23·6
Copper . . .	898·2	Porcelain . .	12·2
Iron . . .	374·3	Fire Clay . .	11·4
Zinc . . .	363	Water . . .	9·

The conducting power of metals may be experienced by holding the point of a pin in the flame of a candle, when the heat is rapidly conducted to the head until it cannot be held by the uncovered fingers.

Atmospheric air and gases have been generally regarded as bad conductors of heat; but recent investigators consider that the atmosphere conducts heat as rapidly as it does sound, but that their effects are rendered almost invisible from the small quantity of ponderable matter in the air.

The conduction of heat through a body is by some regarded as radiated, by others as communicated from particle to particle within the body, and the rapidity of communication regulated by the density and molecular construction of the body.

Radiation.

When a hot body, such as a fire or a mass of metal, is surrounded by other bodies not in immediate contact, but placed at some distance from it, the heat from the hot body radiates from the centre in lines to the colder bodies, with a power inversely as the square of the distance from the centre. The greatest effect is upwards, the least effect is horizontally to the surface. The surface of the bodies receiving heat exercises a marked effect on the quantity absorbed in a given time. It was shown by Leslie that a tin vessel filled with hot water and covered over with lamp black possessed a radiating power = 100, but

Covered with	sealing wax		95
,,	,,	writing paper	98
,,	,,	resin	96
,,	,,	crown glass	91
,,	,,	china ink	88
,,	,,	red lead	80
,,	,,	plumbago or black lead	75
,,	,,	isinglass	75
,,	,,	tarnished lead	45
,,	,,	scratched tin	22
,,	,,	bright lead	19
,,	,,	mercury	20
,,	,,	polished iron	15
,,	,,	sheet tin	12

Here lamp black and white paper have nearly the same power, whilst China ink and black lead have much less. A thermometer is more affected by an equal amount of heat when coated with chalk than when coated with Indian ink, and a thermometer made with coloured spirits rises more, for equal heat, than an uncoloured one.

For instance, painted bodies having a metallic surface from the paint radiate much more than the same bodies not painted. Hammered metallic bodies radiate slower than when less dense, as hammered silver has only a radiating power of 10, but not hammered of 13·7. When the surface of each is scratched the radiating power is inversely affected, for the hammered is 18 and the cast only 11·3. This leads to the inference that radiation depends upon a thin film at the surface regulated by the density, for the increase of rough burnished silver is $\frac{4}{5}$ of that of polished hammered, while the cast rough decreases $\frac{1}{5}$ from that of polished cast silver. The absorbing power of a body is usually reckoned as equal to its radiating power.

Colour was long held to affect radiation, but that is now found untenable. It owed its probability to the observed effects of the heat of the sun in radiating most from black, less from blue, green, red, yellow, and white, in the order in which they stand, when acted upon by heat combined with light. Absorption of ordinary heat without light depends, as has been seen, more upon the nature of the surface than of the colour.

It was also generally supposed that there was some ratio between radiated and conducted heat; but it is now ascertained that it only approximates at low but not at high temperatures, and that at 60 to 120 Cent. it is as 3 to 7, at 60 to 130 Cent. as 3 to 13, and at 60 to 240 Cent. as 3 to 21, whilst on the old law these numbers would have been 6, 9, 12, instead of 7, 13, 21.

The properties of passing heat and light through bodies appear to have little relation, and Mellorie regards them as being inversely to each other. Thus blackened glass passes heat but scarcely any light, and wood passes neither. Of transparent bodies mineral salt passes 92 per cent. of heat, but alum only 12 per cent.

Radiation has therefore been considered as equal in power but inversely to absorption, and that at the same temperature the radiating and absorbing power of bodies are equal. Radiation may be defined to depend upon the facility of decomposing the particles, but absorption upon the inability to reflect them back. Much of the comparative economy of steam boilers depends upon their absorbing power; for no matter how ably the furnace performs its duty, if the heat given off from the fuel cannot be taken up as rapidly as it is produced, then of course economy ceases. The rapidity of production of heat in a locomotive furnace is not favourable for the entire absorption of that heat: hence the advantage of the numerous thin metal tubes to divide and absorb the heat generated in the furnace. It is not the least merit in this class of boilers, that as the velocity increases so does the area of conduction or direct contact of the heat, whilst the area of radiation decreases in the same ratio. For as the draught upon the fire increases so does the length of the flame; consequently not only the fire box, but also a greater or lesser portion of the thin tubes in immediate contact with that flame, absorb heat by conduction, and the remainder of the tubular surface absorbs it by radiation from the passing gases.

Convection.

Convection or carrying is the power possessed by fluids of conveying heat acquired at one place to another place.

In boilers the heat is thus transmitted amongst the water. In the furnace the air carries the unabsorbed heat to the chimney. When the power of convection is much greater than the power of absorption, then the heat evolved during combustion is carried off without producing its proper effect. The greater therefore the absorbing power of any boiler, the greater will be its economy. In locomotive boilers at high velocities, this power of convection increases as the radiating surface decreases, and the loss of heat by convection is in proportion to the velocity of the escaping gases and the shorter distance passed over by them.

In solid bodies heat travels from atom to atom, but in fluid bodies, the heated parts fly off and colder ones take their place until the heat has been diffused. It is only by convection that air carries heat, for if its circulation be stopped it nearly ceases to carry heat. Glass also carries heat slowly, and it is estimated that a square foot of glass exposed on one side to the atmosphere will cool 1·279 cubic feet of air 1° per minute, when it is in contact with the glass, as seen in the condensation of the vapour in the air on it precisely as dew is formed on the grass.

A cast-iron pipe 3 inches diameter, and metal ¼ cooled down 1° in 1·21 min. with a black surface, in 1·25 min.

with an iron surface, and in 1·28 min. with a white painted one.

Reflecting Power.

The reflecting power of different bodies is generally estimated as being inversely as the radiating power, so that if brass reflects 100 parts of heat, silver would reflect 90, and with these others as they stand below.

Brass	100
Silver	90
Tinfoil	85
Block tin	80
Steel	70
Lead	60
Tin foil, softened by mercury	10
Glass	10
Glass, coated with wax	5

Specific Heat.

The specific heat, or the comparative capacity of bodies of equal weight to receive heat, varies widely. Thus, if 1lb. of mercury at 32° be mixed with water at 62°, the temperature will become 61°, or if the mercury had been 62° and the water 32°, the common temperature would have been 33°, showing that the capacity of mercury for heat is about $\frac{1}{30}$ of that of water. It may therefore be considered as the ratio of the heat in a given weight or volume to those of the standard body. Iron shows a specific heat of ·113 or $\frac{1}{9}$ that of water, and steam ·847. Water is usually made the standard of comparison for ponderous bodies, and air for gaseous bodies. The capacity of bodies for heat is also tested by the quantity of ice they will melt: thus, equal weights of iron and lead, heated to 100° would melt 11 grains by the iron, and only 3 grains by the lead, each falling to 95°. The same test applied to fuel has given the following results.

1 lb. of good coal	melts	90 lbs.	of ice.
„ coke	„	84 lbs.	„
„ wood	„	32 lbs.	„
„ wood charcoal	„	95 lbs.	„
„ peat	„	18 lbs.	„

It may be mentioned here that it was on this plan that Dr. Arnott tested the quantity of heat passing from a common fire up the chimney, and by the quantities of ice melted he found it more than the whole heat radiated out into the room, which melted less ice than the heat carried up the chimney.

The following is a table of a few specific heats.

Table No. 11.

SPECIFIC HEAT IN DIFFERENT BODIES.

	Regnault.	Dulong.		
Iron	·1137	·110	Hydrogen	3·2936
Copper	·0951	·0949	Water	1·
Zinc	·0955	·0927	Steam	·847
Nickel	·1086	·1035	Alcohol	·600 to ·700
Cobalt	·1069	·1498	Ether	·6600
Platinum	·0324	·0314	Oil	·520
Gold	·0324	·0298	Air	·2669
Sulphur	·2026	·1880	Nitrogen	·2754
Carbon	·2411	·25	Oxygen	·2361
Phosphorus	·1887	·385	Carbonic acid	·2210
Iodine	·05412	·089	„ oxide	·2884
Arsenic	·0814	·081	Charcoal	·2631
Lead	·0314	·0293	Oil of turpentine	·426
Bismuth	·0308	·0288	Sulphuric acid	·333
Antimony	·0507	·0507	Nitric acid	·126
Indian Tin	·05623	·0514	Iron at 212°	·110
Mercury	·0333	·0330	„ 392°	·115
Steel	·118		„ 372°	·122
Brass	·094		„ 662°	·126
Glass	·177		„ carbonate of	·1819
Salt	·225			
Marble	·205		Zinc „	·1712

The difference in the quantity of specific heat by different experimenters arises from the delicate nature of the experiments and the manner of performing them, in which the minutest error becomes magnified when generalized.

The capacity for heat increases with the temperature, as seen in iron, and in cooling a greater amount of heat is given out in cooling down an equal number of degrees at a high than at a low temperature.

To raise 1 lb. of water from 32° to 212° or 180° requires as much heat as would raise 3·72 lbs of air through the same range. Strictly it is as ·2669 is to 1.

Relative Heat.

Specific heat is by equal weights of the compared bodies, but relative heat is by equal volumes. Thus the specific heat of steam is only ·847, but its relative heat is only $\frac{1}{228}$ that of an equal volume of water, and would lose as much heat in one minute as the water would do in 228 minutes. Relative heat is therefore directly as its specific heat and volume.

With gaseous bodies the specific heat is inversely as their specific gravity; hence equal quantities of such gases contain an equal quantity of heat less their specific gravity. As the relative weights of equal volumes of gas are inversely as their specific gravity, equal volumes will have equal relative heats When mechanically mixed, such as the oxygen aud nitrogen of the air, or the heat and water in steam, though of different densities, yet they have equal relative heat. When gases are chemically combined, they have a different relative heat above that of air, and each gas has its own relative heat, of which air is the unit of comparison. The relative heat of air to water is 0·2669, which multiplied into any aerial comparative exponent would give the comparison with water similarly to ponderous bodies.

Combustion, or the Production of Heat.

Heat appears to be a compound derived from the union of a combustible with an incombustible, which supports or supplies the constituent part necessary to complete combustion, and without which definite supply combustion is imperfect. This combination infers different qualities of the two ingredients in the compound of heat. Strictly, the process of combustion is complex, and only partially understood. As far as regards its ordinary operation in the steam-boiler fireplace, we will endeavour to convey a clear exposition of its more important features.

A coal for instance thrown on a fire evolves amongst others, the two principal combustibles of carbon and hydrogen, which uniting with the oxygen of the air—an incombustible yet a necessary supporter of a fire—produces heat and light at the same time. Simple as this may appear, its analysis is yet a complicated chemical problem. The chief agents operating in the furnace are carbon, hydrogen and oxygen, and their union in certain proportions produces other bodies, as water or steam, carbonic oxide, carbonic acid, besides others of less practical importance.

Combustibles and Incombustibles.

A combustible body is one which actually burns, such as carbon. An incombustible body is one that does not itself burn. A supporter of combustion is one that does not burn, but gives strength and support to one that does burn, such as oxygen, which supports carbon in producing heat. A common fire exhibits the union of the carbon of the fuel and the oxygen of the air. A gas light exhibits the union of carbon, hydrogen, and oxygen to produce both heat and light. In neither process is the oxygen burnt, but only the combustibles, carbon and hydrogen. In all ordinary circumstances oxygen is therefore an indispensable element of combustion, and its proper supply a question of the first importance to economy of fuel. For instance, if only 8 parts of oxygen are admitted for each 6 parts of carbon evolved from the fuel, the combustion is very imperfect, and much of the heat of the fuel passes off in combustible gases, of which carbonic oxide is the chief. If, however, 16 parts of oxygen are admitted to combine with 6 parts of carbon, the combustion is 70 per cent. better than the last, producing steam and carbonic acid as the products of perfect combustion. Under the ordinary pressure of the atmosphere, oxygen is the supporter, and carbon and hydrogen the combustibles, but in a vacuum, or under the intense action of the oxy-hydrogen blastpipe, invented by my friend Goldsworthy Gurney, Esq., and now attracting so much notice in the Crystal Palace—this natural order is reversed, and oxygen becomes the combustible and carbon the supporter of combustion.

The following are the usually received definitions of chemical combination, mechanical mixture and the elements of combustion.

Chemical Combinations.

When two bodies unite to form a third body distinct from either of the combining bodies, this is called chemical union, as when carbon and oxygen unite to form heat, carbonic oxide or carbonic acid, or with hydrogen to form water.

Mechanical Mixtures.

A mechanical mixture is one where the bodies have been brought together, but each retains its original qualities, such as sand and water, or the oxygen and nitrogen of the air, or heat and water in steam, all of which can be readily separated and restored to their original state again.

Atmosphere.

This important body which surrounds us, and supplies the oxygen, or *life* of our breath, besides its other invaluable features, is a mechanical mixture of one-fifth part of oxygen and four-fifth parts of nitrogen, sometimes called azote. The latter dilutes the former, and renders it adapted to the constitution of man and the animal creation; and but for this dilution of the oxygen by the nitrogen, constituted as we are, life would be an accelerated but short course, similar to the brilliance exhibited by a wax taper when plunged into a jar of oxygen on the lecture table. Oxygen is therefore the principal supporter of both life and combustion; but the peculiar uses of nitrogen are only clearly understood as indispensable to vegetation. An ordinary iron furnace is estimated to require 310 tons of air in 24 hours, or as much as 20,000 men. That it is the oxygen which changes or supports ordinary combustion may be shown by covering an ordinary candle with a bell glass whose lower edge rests in water, to prevent a further supply of air inside the glass. As the enclosed oxygen is changed the flame grows less and less until it is extinguished, and the contents are found to be nitrogen apparently unaltered, hydrogen and carbonic acid. 100 cubic inches of air weigh 31 grains.

Oxygen.

This gas was discovered by Dr. Priestley in 1774, and is considered to be one of the most abundant bodies in nature. It is a permanent colourless transparent gas without smell, and 1·11 times heavier than air, and 100 cubic inches weigh 34·184 grains. It combines with many other bodies in a variety of ways, forming very distinctive compounds. For ordinary combustion and breathing it is supplied from the atmosphere, but for the lecture-room it can be readily obtained in several ways, one of which is by heating the chlorate of potash, and collecting the gas given off in a bladder or jar. If a taper with a single spark of fire left on its wick be placed in any jar of oxygen, it immediately burns forth with splendour, and iron when introduced is melted down in a shower of dazzling scintillations, forming oxide of iron.

Ordinary rust is also oxide of iron formed from the slow combustion of atmospheric temperature, whilst the intense temperature of carbon and pure oxygen produce rapid combustion, and the smith's forge is only another degree of the same process. Phosphorus introduced amongst oxygen produces a volume of painfully brilliant light forming phosphoric acid.

The oxy-hydrogen light, as invented by Mr. Gurney, improved by Mr. Beechy, and exhibited by Mr. Abraham of Liverpool in the Great Exhibition, consists in bringing equivalent quantities of oxygen and hydrogen gases into a burner and igniting them, when they evolve vivid combustion and intense heat, melting all common metals with great ease. Lime, however, resists its fusive power, but evolves the most brilliant light then known, which is employed in the Polytechnic Institution for their microscopic views. Recently, however, a still more luminous light is produced by the action of electricity on two pieces of charcoal, and M. Lessel and Co. exhibit one of great illuminating power at the Crystal Palace, whose light when tried by the prism shows the solar spectrum rays of the light of the sun, viz., red, orange, yellow, green, blue, indigo, and violet.

Nitrogen.

This body neither supports life nor combustion. It is lighter than air, has no taste or smell, is little absorbed by water, and has no effect upon lime water. Its specific gravity is ·972 that of air, or 100 cubic inches weigh 30·15 grains. Although nitrogen has some properties in common with carbonic acid, one of the products of perfect combustion, it has also dissimilar ones, besides being an elementary body, while carbonic acid is a compound of oxygen and carbon. Nitrogen is necessary to life. Carbonic acid is poisonous. Protoxide of nitrogen forms the well-known laughing gas, which produces such an exhilarating flow of spirits and muscular energy, by a few inhalations of it, and its specific gravity is 1·527 that of air, or 100 cubic inches = 47·37 grains.

Carbon.

This is a finely-divided pulverulent mineral body in its ordinary state, forming the basis of most fuels, and found in many different forms; as it is obtained by various processes—from oil lamps, as lamp black; from coal, as coke; and from wood, as charcoal. It is the mineral particles of carbon in a state of combustion which render flame luminous from either gas, oil, or candles. Tallow or wax candles are a compound of carbon, oxygen and hydrogen. The diamond is pure carbon in a crystalline state, possessing the singular property of reflecting all the light which falls upon it at an angle of about 24°, whilst artificial gems only reflect half that light. The diamond is highly valued, and in much esteem as an article of dress, or to adorn an imperial crown. Amongst the many attractions of the National Exhibition, her gracious Majesty's three specimens of pure carbon in the celebrated Koh-i-noor and two other diamonds, are none of the least.

To the general reader the following particulars of the "Mountain of light," (Koh-i-noor) may possess interest.

The Koh-i-noor has no ordinary history, having frequently changed owners, either by the fortunes of war or intrigue, and is now little more than a third of its original weight, being reduced, by the unskilfulness of Hortense Berghere, a Venetian lapidary, from 800 to 279 carats. Its original value was estimated at 3½ millions; it is now estimated at only half a million, for diamonds rapidly increase in value with size. It first received notice when belonging to the Mogul Princes, and was obtained by Nadir Shah when he plundered Delhi, to the extent, it is said, of 40,000,000*l.* On his assassination it disappeared for a time, until Ahmed Shah's time, and it passed from his successor, Shah Soojah, to Runjeet Singh, on whose death it remained at Lahore until it was taken by the British during the last Sikh war, and is now exhibited in Great

Britain's Industrial Palace. It is not now the largest diamond known, although originally it was so, as that of the Rajah of Mattan in India weighs 367 carats, or 3 ounces troy. A few other celebrated pieces of crystallized carbon are, the Empress of Russia's, weighing 193 carats, and valued at 90,000*l*., the Emperor of Austria's, weighing 139 carats, valued at 100,000*l*., and the Orleans or Pitt diamond, weighing 136 carats, and valued at 164,000*l*.

Such are the values of small pieces of carbon, as found in the diamond, but intrinsically, for national wealth, they will not bear an instant's comparison with that form of carbon which composes from 60 to 90 per cent. of coals. The former is an absorber of wealth otherwise existing; the latter is a producer of wealth throughout the world, and in this country forms the basis of our power and progress, without which the Crystal Palace had not been called into existence.

Carbon also unites with iron to form steel, and with hydrogen to form the common street gas, called carburetted hydrogen gas. Analysts tell us that the diamond and its converse, lamp black, are both pure carbon; and charcoal and coke are other well-known forms of carbon, obtained by burning them with a partial supply of air or oxygen. Coals are a compound of carbon, hydrogen, nitrogen and oxygen. Carbon is considered as the next most abundant body in nature to oxygen. In the furnace the carbon of the fuel unites with the oxygen of the air to produce heat. If the supply of air is correctly regulated there will be perfect combustion producing carbonic acid, but if the supply of air be deficient, combustion will be imperfect, and carbonic oxide produced.

Carbonic Acid Gas.

When air passes through a fire, this gas is formed by the combustion of 16 parts of oxygen and 6 parts of carbon. Its specific gravity is 1·523 that of air, and it forms 44 per cent of lime. It is fatal to life, as exemplified in the black hole of Calcutta, when about 140 men died in one night by breathing the same air again and again until the oxygen in it had become this gas. It also extinguishes fire, as has been so ably shown this year by Mr. Gurney, forcing it into the burning Sauchic coal mine, and putting out a fire of about 26 acres area and 30 years duration.

Carbonic Oxide.

This is a colourless, transparent, combustible gas, which burns with a pale blue flame, as may be seen at times on opening a locomotive fire-box door. Its presence in a furnace is evidence of imperfect combustion, from a deficient supply of air, as it indicates that only 8 parts of oxygen instead of 16 parts have united with 6 parts of carbon, requiring as much more to produce complete combustion.

Hydrogen.

Hydrogen is the source of all common flame, although it extinguishes a light plunged into it, but in doing so takes fire itself and burns at the edge of the vessel, similar to its issuing from a gas burner, when it combines with the oxygen of the air and gives out a brilliant flame, but does not enter into the tube or burner where the air is not in contact to supply the necessary oxygen.

It is the lightest known body in nature, being 16 times lighter, for equal volumes, than oxygen, and is a permanent, yet combustible gas, giving out much heat. It was discovered by Cavendish in 1766, and being $14\frac{1}{2}$ times lighter than air, it is employed in baloons. In our gas establishments it is now distilled from coal in large quantities, and combined with carbon for illuminating streets, shops, and dwelling houses. It is not itself innoxious to life, but does not support it, and when combined with sulphur, it becomes explosive, and too frequently produces the most lamentable results in our coal mines. By passing a current of steam through a hot iron tube partly filled with filings, hydrogen gas is given off, and burns with a pale yellow flame. It also combines with oxygen to form water according to Watt's composition of that body. But the recent experiments of Payne seem to indicate that water may be decomposed by negative electricity into hydrogen, and by positive electricity into oxygen; and by both poles being applied, both hydrogen and oxygen are produced from the water, as ordinarily decomposed.

Comparative Heat of Carbon and Hydrogen.

Dulong estimates that 1 lb. of hydrogen will give out about 4·707 times as much heat as 1 lb. of carbon. In ordinary combustion there is rarely found any provision made to effectually consume the hydrogen evolved in the furnace, so that it has been usual to take the quantity of carbon in any coals or coke as the index of their heating powers. If hydrogen gas come to be cheaply evolved, or furnaces arranged to partly consume what is evolved, the theoretical and practical duty of fuel would be proportionally increased. If a unit of heat be taken as the quantity which would raise 1 lb. of water 1° Fah., 1 lb. of carbon is valued as equal to 13268 such units, and 1 lb. of hydrogen as equal to 62470 units, or 4·7 to 1 of carbon. In ordinary coal fires of engines the air is only admitted by the fire grate, and after passing through the fire, is consequently unfitted to totally consume the hydrogen gas evolved, which may thus pass off as lost heat, and what portion may be consumed will scarcely balance the heat necessary to its production.

Heat from Combustion.

This is variously estimated by different authorities. Despretz gives the following values on lbs. of water raised 180° by 1 lb. of each fuel.

1 lb. of		Lbs. of water from 32° to 212°
Hydrogen	heat	236·4
Olive oil	,, ...	90 to 95
Ether	,, ...	80
Pure charcoal	,, ...	78
Wood charcoal	,, ...	75
Alcohol	,, ...	67·5
Coals	,, ...	60
Baked wood	,, ...	36

Process of Combustion in a Furnace.

For raising steam the process of combustion consists in evolving and completely consuming the combustible elements of either coal, coke, or other fuel employed, to produce heat, which may be divided into four different stages of the process:

First stage.—Application of existing heat to evolve the constituent gases of the fuel. In coals this is principally carburetted hydrogen.

Second part.—Application or employment of existing heat to separate the carbon from the hydrogen.

Third part.—Further employment of existing heat to increase the temperature of the two evolved combustibles, carbon and hydrogen, until they reach the heat necessary for combination with the oxygen of the air. If this heat is not obtained chemical union does not take place, and combustion is imperfect.

Fourth and last part.—The union of the oxygen of the air, with the carbon and hydrogen of the furnace in their proper equivalents, when intense heat is generated by the exchange of the electrical heat in each, and light is also given off from the ignited carbon. Sir H. Davy estimated this heat as greater than the white heat of metals.

In the first three stages of combustion heat is absorbed by the fuel, and only in the last stage of the process is that absorption replaced with greatly increased effects.

When the chemical atoms of heat are not united in their proper equivalents, then carbonic oxide, carburetted hydrogen and other combustible gases escape invisibly, with a corresponding loss of heat from the fuel. When the proper union takes place then only steam, carbonic acid and nitrogen escape, which, being the products of perfect combustion, are all incombustible, and also incapable of supporting combustion.

The principal products therefore of perfect combustion are:

Steam, invisible and incombustible.

Carbonic acid, invisible and incombustible.

The products of imperfect combustion are:

Carbonic oxide, invisible but combustible.

Smoke, partly invisible and partly incombustible.

Steam is formed from the hydrogen gas given out by the coals combining with its equivalent of oxygen from the air, in the ratio of 2 volumes of hydrogen to 1 of oxygen, or by weight as 1 to 8, as already explained.

Carbonic acid is formed from the carbon of the coals combining with its equivalent of oxygen from the air, in the proportion of 2 volumes of oxygen to 1 volume of carbon, or by weight, as 16 to 6.

Carbonic oxide is formed from the carbonic acid first produced, receiving another volume of carbon in passing through the fire, which last volume of carbon is unconsumed, and forms the combustible carbonic oxide, whilst carbonic acid, having had its carbon consumed, is incombustible.

Smoke is formed from the hydrogen and carbon which have not received their respective equivalents of oxygen from the air, and thus pass off unconsumed. The colour of the smoke depends upon the carbon passing off in its dark pulverized state, but the quantity of heat carried away is not dependent upon the carbon alone, but also upon the invisible but combustible gases (hydrogen and carbonic oxide), so that whilst the colour may indicate the amount of carbon in the smoke, it does not indicate the amount of heat lost; hence the smokeless locomotive may, and does unobservedly lose more heat in this way than is lost from the combustion of coals in stationary-engine furnaces.

Besides the demands of the carbon for the oxygen admitted to the furnace, the hydrogen evolved also requires its equivalent, and could this be fairly carried out in the locomotive furnace; the oxy-hydrogen light is sufficient evidence of the intense heat which would be obtained. But where there is no provision for the proper supply of oxygen to such gases it is evident that the hydrogen evolved must nearly all pass off unconsumed.

The hydrogen requires one equivalent to produce steam, and the carbon another equivalent to produce carbonic acid. Along with these two equivalents of oxygen the air contains eight equivalents of nitrogen (of no known use in combustion), also passing through the furnace, consequently requiring 10 times as much air as there are gases to be consumed. When less than the proper quantity of air is supplied, hydrogen, from its greater affinity for oxygen than carbon, will take up its equivalent for steam, leaving the carbon to pass off partly unconsumed, as carbonic oxide. An excess of air is, however, as injurious by its tendency to lower the temperature of the evolved gases below the point where the chemical union takes place, and requires to be guarded against in the well-arranged and well-managed fire place.

A practical and familiar instance of imperfect combustion is exhibited when a lamp smokes, and the unconsumed carbon is deposited in "blacks" all round it. When the evolution of carbon is lessened by lowering the wick to meet the supply of oxygen, the carbon is all consumed and the smoke ceases. What takes place with a lamp also occurs in a furnace, so that the proper supply of air is a primary consideration, both as regards its quantity, and its mode of admission to a fire; for both affect the economical results.

In locomotive furnaces for coke the air is usually admitted through the fire grate, and before it passes through a thick body of red-hot fuel, the oxygen is either all absorbed or so deteriorated, that it is incapable of combining with the hydrogen, which thus passes off unconsumed, and may be occasionally observed to ignite at the top of a locomotive chimney, when it obtains its equivalent of oxygen from the surrounding atmosphere. Such ignition of course only takes place when the steam is shut off, as its condensation saturates or cools the gases below the temperature of chemical union.

The economical generation of heat is therefore a process entirely distinct from the use made of that heat afterwards, just as the generation of steam is an entirely different question from its employment in an engine.

Combustion may be perfect, but absorption of heat by a boiler may be inferior, and consequently evaporation of water bear a low ratio to the fuel consumed. To arrange the construction of a boiler with rapidly absorbing materials is the principle aimed at by our best boiler-makers, to obtain increased evaporative power.

The human body has been frequently compared to a furnace, and the process of digestion to combustion, and it is a correct description, for oxygen is the active agent in both processes. In placing animal food in a red-hot platinum crucible, its carbon unites with oxygen to form carbonic acid; its hydrogen with oxygen to form water; its nitrogen either escapes free, or unites with hydrogen to form ammonia, leaving behind only some salts partly soluble and partly insoluble in water.

Now in the living animal frame these processes are in regular operation.

The food is the fuel, evolving carbon and hydrogen, which, combining with the oxygen inhaled by the lungs from the air, is burnt, and the products of combustion, steam and carbonic acid—are exhaled from the lungs. As in the experiment with the enclosed candle, so in the human body, the nitrogen of the air appears to be inhaled and exhaled without apparent alteration. The nitrogen and soluble mineral portions of the food pass off as salts of ammonia in the urine, and the insoluble portions or "clinkers" of the food require, as is well known, especially to those suffering from dyspepsia, to be as regularly cleared off as do the residue from the fire-grate.

Sir H. Davy found that he required for respiration during 24 hours, 45,504 cubic inches, or 15,751 grains of oxygen, which produced 31,680 cubic inches, or 17,811 grains of carbonic acid, of which 4853 grains were carbon. Since oxygen is only $\frac{1}{5}$ of the air, the volume of air inhaled would be $45{,}504 \times 5 = 227{,}520$ cubic inches in 24 hours. The mean carbon issuing from the lungs of an ordinary-sized man is about 130 grains per hour, or rather more than 7 ounces daily, besides what passes off by cutaneous perspiration. In a state of repose, however, Savaser found that the consumption of oxygen was only $\frac{7}{10}$ that of a state of activity: hence sleep is known to be "tired nature's sweet restorer," by its then allowing the human furnace a little rest; for it is a law, that rapid combustion is equally fatal to the iron and to the vital furnace.

The average quantity of air inhaled at once by a man is about 20 cubic inches, and as one fifth of it again leaves the lungs in a poisonous state (carbonic acid) it vitiates any confined atmosphere unless ventilation steps in to prevent injurious consequences more or less rapid—as the supply of air may be more or less imperfect.

The animal heat of combustion is about 98° Fah., and is of course slow compared to an iron furnace of 3479° Fah.; still both processes are chemically alike, and pure air is as needful a supply to the human furnace as it is an indispensable one to the locomotive furnace.

The following table of the temperature of combustion in man and other living species may be instructive.

Table No. 12.

HEAT OF COMBUSTION IN THE LIVING FURNACE.

Class.	Temp. of Atmos. Fah.	Temp. of Animal. Fah.	Class.	Temp of Atmos. Fah.	Temp. of Animal. Fah.
Man . .	Various.	98	Crow . .	67	104
Monkey . .	86	102	Frog . .	76	77
Hare . .	80	100	Green Serpent	81½	88½
Tiger . .	80	100	Brown ditto .	82½	84½
Dog . .	80	102	Brown Adder	82½	90
Cat . . .	77	102	Shark . .	74	77
Horse . .	79	101	Trout . .	55½	57½
Ox . . .	79	102	Flying Fish .	77½	77¾
Kite . .	80	100	Oyster . .	81	81
Sparrow .	80	108	Lobster .	79¼	79
Pigeon . .	78	109	Crab . .	72	72
Hen . .	78	110	Beetle . .	76	77
Goose . .	78	106	Glow-worm .	72	73½
Drake . .	78	110	Wasp . .	71½	76

The temperature of the animal body appears to be regulated by its own internal combustion without reference to the surrounding medium. For instance, man is found to possess the same heat under all climes and temperatures supportable by the human body.

It is estimated that the heat given off by the human body in 24 hours would raise 63 lbs. of water from the freezing to the boiling point, yet the carbon thrown off from the lungs is estimated as only equal to heat 36½ lbs. of water, through the same range. The difference is supposed to be due to the action of the muscles and the nerves.

Application of Heat to produce Steam or Evaporation.

The comparative effect of heat to produce steam in a boiler depends upon the ratio of the absorbing and transmitting power to the velocity of the escaping products of combustion.

For if the velocity be greater than the absorption and transmission of the passing heat to the water, then there will be a corresponding loss of heat. In the locomotive boiler with a rapidly escaping current only from $\frac{1}{10}$ to $\frac{1}{16}$ of the absorbing surface is by direct contact at ordinary speeds of the engine, and the remainder at right angles to the escaping current of heat. At high velocities the surface of contact will be increased to about $\frac{1}{3}$ or $\frac{1}{2}$, whilst the velocity of the escaping gases will be also increased, over a decreased length of tubes. Therefore as the velocity is increased the economy of fuel is decreased, from the failure of the absorbing and transmitting power of the boilers to convey more heat in less time to the water.

The comparative heat transmitted by conduction, radiation, and convection may be tested by alternately placing a thermometer in contact with the flame of a candle, next by its side, then over the top of the flame, and noting the temperature at each of the three positions. Or if the hand be cautiously substituted where a thermometer may not be convenient, the respective differences will be sensibly indicated, and give a clear idea of the heat lost by convection, when its velocity is considerable, and the absorbing space limited. In this respect Stephenson's and England's long boilers have an evident advantage over shorter boilers, where the diameters of the tubes do not offer sensible obstruction, for the largest portion of locomotive heating surface is on the worst or radiatory portions, at slow velocities, but decreasing as the increase of velocity extends the flames through the tubes. The experiments made by Mr. G. Stephenson, many years ago, showing the comparative evaporative ratio between the fire box and tubes of an engine at rest, as 3 to 1, would scarcely apply to an engine at very high speeds, since the relative conducting or radiating surfaces are not uniform, but vary with the velocity of the engine and heating power of the fuel. With a low velocity these surfaces might be more uniform, if the flame acted only on the fire-box.

The economical evaporation of water into steam depends therefore, first, upon perfect combustion; and, secondly, upon the absorbing and transmitting power of the boiler.

Where these powers are equal, the effects would be in the ratio of the surfaces of conducted and radiated heat, but where unequal in the ratio of their transmitting power only. Careful management of the fire to prevent "air holes" burning through in places, a due regard to the air-admission spaces being uniform, and a steady regular supply of fuel, have considerable effects upon the economical results from any boiler. A clear level fire, kept fed by regular-sized pieces of fuel, and the fire-grate kept free from clinkers, all contribute to economy, and should be practised. To aid the fireman or driver in their duties, as well as for the higher objects of research, there should be in every locomotive boiler one glass pane in the fire door, and one in the smoke-box door, that both the fire and the state of the escaping heat might be seen, without opening either door, until such was really necessary. The chilly effect of opening the fire door in checking the production of steam is well known, and might be so far avoided whilst the experienced eye would soon detect whether combustion was or was not perfect, and act accordingly. There is no practical difficulty in doing so, for both in this country and in America it has been done by our best experimenters, and, of course, could be done in daily practice with good results. A good self-acting feeder of fuel is desirable.

Theories of Heat.

However well known may be the effects of heat, or the sensation it produces—whilst exhibiting its gentle docility in supplying the many wants of man, its destructive powers in conflagrations, explosion, or artillery; its potent sublimity in the thunder-storm; its awe-inspiring force in the heaving earthquake; its formidable grandeur when issuing from the volcanic safety-valves of the great globular boiler on which we live; and the immense magnitude of its former operation in forming the shell of that boiler, all proving its power and influence in creation—its real nature remains a matter of doubt, for its subtilty and extensive range of action have as yet defeated definite analysis. This may appear singular to those who have only regarded heat as a common-place agent, since it is found still determinable at 480° below Fah. zero, whilst the sun and electricity attest its concentrated energies. This intense heat and light are strikingly exemplified in the Great Exhibition, as already referred to. However, as correctly observed by a recent investigator of its phenomena,* "Every one knows the sensation of heat, though it may be difficult to describe it."

The following is a brief outline of the prevailing theories of its nature, followed by a few practical remarks on them.

There are two theories of heat which more particularly engage attention, with a third, derived from the others. The prevailing one is that heat is a fluid of so subtle a nature as to preclude any direct investigation of its nature, which fluid is called caloric. The next theory is, that heat is not a material fluid, but is the effect of motion, and its intensity regulated by the momentum of the atoms in motion. The third theory is that heat is the motion of an elastic fluid universally diffused.

Calorific Theory of Heat.

This theory assumes that heat is a material fluid called caloric, which is communicated from one body to another by conduction, radiation, and convection.

This theory is also accompanied by the doctrine of latent heat, to account for the heat contained in any body not

* Herapath.

measurable by the thermometer, and therefore difficult to analyze as a property of a material body.

Considering the prominence which the doctrine of latent heat has long borne in reference to steam, it will be necessary to fully explain it.

Latent Heat.

Latent or hidden heat is that heat which is not measurable by a thermometer. For example, the temperature of ice is 32°, but it requires 140° of heat to convert that ice into water again, which is called the latent heat of ice, because the 140° are not indicated by the thermometer.

Water kept quite still has been cooled to 5°, yet retained its liquidity, but on motion being given to it, a great portion of it suddenly became ice at the increased temperature of 32°. The difference of 27° is called the latent heat of water at 5°.

At 212° water begins to pass off into steam, but it requires the same amount of heat to be continued nearly six times as long as raised the water to 212° to convert it all into steam, which is thus called its latent heat. Taking the temperature of water as 52° we have $212° - 52 = 160°$ of heat added to the water to raise it to the boiling point, and $160 \times 6 = 960°$ usually reckoned as 1000° for the latent heat of steam under the pressure of the atmosphere, but strictly 965·7°.

Regnault found, from an able series of experiments, from 1 up to 13·6 atmospheres, the total heat of steam increase from 1170° up to 1230° Fahr., while the diffused heat decreased from 973° to 878°. The Franklin Institute found the diffused or latent heat of steam of 212° to 215° temperature from 995·3 to 1038·5°.

Motion Theory of Heat.

This theory is, that heat is an effect measured by the motion of particles having power to communicate that motion to other particles or to other bodies. If the motion be greater in one part than in another part of the same body, the heat will be unequal, but with a tendency to equalize the temperature throughout the mass. The power to heat would be as the temperature directly and the number of particles in motion conjointly. By bringing a thermometer in contact with a body, the motion would be communicated to the mercury, and the amount of motion be read off in the scale of parts as usual. Atoms or particles of bodies moving towards each other would unite, forming a smaller number of particles with more heat for each, but if the motion tended to separate the atoms, the temperature would decrease with the decreased momentum.

When water becomes ice, the particles combine, and the motion or temperature remains uniform; or when water becomes steam the atoms are divided with a less temperature for each, but an increased aggregate temperature.

There is, therefore, a growing disposition to regard heat as an effect similar to light, heat, space, or electricity, and that this effect arises from motion.

Theory of Heat as a Fluid in Motion.

This is merely a combination of the leading features of the calorific and motion theories, evidently based on the idea so natural to all finite minds, that by some finite agent the effect of heat might be accomplished. This theory regards heat as a fluid in vibratory motion capable of producing all the known results or phenomena attending the evolution of heat.

It differs from the motion theory by regarding the fluid as material, but agrees with it in all other points as to the effect of motion in developing heat. The remarks, therefore, on the motion theory will apply to this one, excepting the materiality of the agent, which is the difficulty required to be solved—whether heat is or is not a material body.

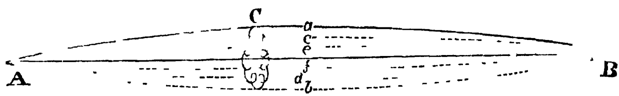
Remarks on Theories of Heat.

To an ordinary observer there is a difficulty in reconciling the doctrine of latent heat with the simple laws of nature, yet it is no ordinary matter to differ from the many able men who have supported this doctrine. A conviction however that as regards steam it is untenable, leads to the following remarks, being submitted with every deference to those who take an opposite view.

The usual definition of "latent" is *hidden*, and that the heat in any body which is not measurable by a thermometer is latent heat. Now it may be observed that the heat-producing properties of bodies differ greatly, and are quite distinct from their sensible heat. Thus stones from the quarry and coals from the mine, have little difference of thermometric heat, but on combination with oxygen their power of generating heat is very different. If this property of bodies evolving either heat or other body peculiar to their atomic formation be considered as a latent or hidden power, it should follow by parity of reasoning that, the effects of sound, or light produced by a change of circumstances from any other body would be the latent power of such body. For example, a piece of artillery fired along a narrow street, produces a sound accompanied by a motion of the air sufficient to break the glass in *closed* windows, but not in open ones, which leave a passage for that motion to exert its force on the more resisting walls. Minute calculations are given to inform us that the harmonious sounds of musical instruments are the effects of definite numbers of vibrations in a second of time, that the range of these vibrations for vocal music are for a male voice from 384 to 1266, and for a female voice from 1152 to 3240; that the highest note in music (five octaves above the middle C of the piano) is due to 8192 vibrations in a second, the next C 4096, the third C 2048, and so on to 16 vibrations, as the lowest note in music. The sharpness of the sound being due to the number of times the vibrations strike the air in a second.

Fig No. 8, shows the theory of the vibration of a violin

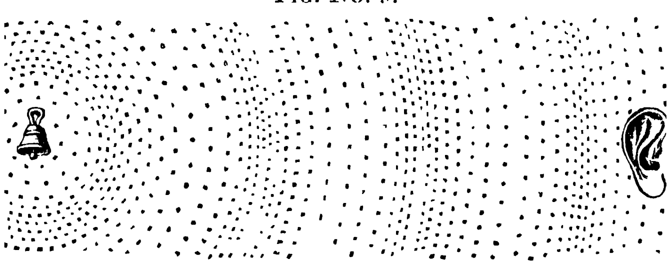
FIG. No. 8.



string, A B, which is estimated to produce 240 vibrations, if touched by the finger at a certain distance from the bow line; but if the string is pressed one half nearer to that line the sound is an octave higher, and the number of vibrations doubled, or 480 per second. The motion is, however, supposed not to be in uniform lines passing and repassing the centre lines, but more like the curved outline at C, as in Fig. No. 8.

Fig. No. 9, shows the theory of the motion produced by

FIG. No. 9.



a bell, every vibration sending a spherical wave in every direction, resembling those circular ones on the surface of a smooth sheet of water when a pebble is thrown in. The more regular these waves the more musical the sound, whilst a series of irregular waves produce a noise, but not a musical sound. A shrill whistle is due to several thousand vibrations in a minute.*

Now, if sound be the effect of motion, and the variation of

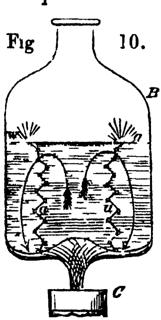
* Tomlinson's Rudimentary Pneumatics.

sounds results from the number, momentum, or delicacy of these motions, heat may be equally the effect of motion, and its quantity due to the same changes of that motion as sound. For the animating tones produced by the accomplished performer from a pianoforte, organ, or violin are equally hidden or latent, before being evoked by the impressive touch of the skilful artist, as is the heating power of fuel before ignition calls it forth.

It seems, therefore, more in accordance with the simple laws of nature, to regard heat and sound as both phenomena called forth by motion, and amenable to the same general law. The power required to produce the motion of sound, is fairly represented by the force of heat required to give a higher degree of motion or temperature, so that the power of touch, or of mechanical agency in musical instruments, has its equivalent in the quantity of heat requisite to produce certain changes of temperature in given bodies, and will be measured by the resistance to greater motion of the particular body.

It is usually advanced as a proof of the latent heat of steam that no additional heat imparted to the water increases its temperature beyond that due to the pressure on its surface, whilst six times the heat added to boil it is required to make that water into steam of the same temperature as itself. This, however, can easily be shown to be a good example of the law of equal diffusion by a very simple experiment.

Fig 10.



Water Boiling.

Let the glass phial B, Fig. No. 10, represent a boiler filled with water to W, and placed over the flame of the candle C. At first there is no visible circulation in the water, but it soon begins, and continues to increase until small globules are observed to form at the bottom from some of the descending atoms of water, and as soon as formed dart off in an irregular zigzag ascent to the surface, retaining their spherical form. The circulation increases until ebullition commences, and larger and more numerous globules are formed, crossing each other's paths in their ascent to the top, where they expand into steam nearly 1700 times more voluminous than the water enclosing the globule. In the figure only two of these atoms of water, *a*, *a*, *a*, *a*, are represented, to make the process more obvious.

The questions then are, what are these globules? and, why are they in such haste to escape from the water? The reply which naturally occurs is, that these globules are ascending atoms of heat instantly caught up and surrounded by their equivalents of water, forming steam of a specific gravity about 1300 times lighter than the water, and about 1·6 times lighter than the air pressing on the water; hence their hurried irregular ascent is due to their less specific gravity struggling against the friction of the resisting water to their escape from confinement. These zigzag ascents of the little globules of steam bear some resemblance to the path of the forked lightning darting through the atmosphere, and since the friction of condensing steam issuing through small orifices is abundantly proved by Armstrong's hydro-electric boiler to produce vast quantities of electricity, is it impossible that the friction of these small globules through the water may not also evolve electricity? Armstrong's electric boiler artificially divides the condensing steam to produce friction; boiling naturally divides the water into its equivalent atoms, of separate ascent, producing a vast amount of frictional resistance to the escape of the atom of heat and its surrounding film of water. Instead therefore of the heat remaining in the water, it is evident that as soon as the water reaches the temperature of combination for steam, the atoms of heat which penetrate the boiler are separately surrounded and carried out of the water altogether, to be diffused amongst the steam, but are neither lost nor hidden. For if it only requires six atoms of heat to maintain an equal temperature in 1700 spaces of steam, as one atom of heat did over one space of water, we have $\frac{1700}{6} = 283$ as the relative diffusion and activity of the heat in its new field.

Since condensation recalls both the heat and water to their original spaces again, it proves their diffusion, for it could not be expected that the quantity of heat which would raise the temperature of one room 10°, would equally raise the temperature of 1700 equal-sized rooms; yet such appears to be the inference drawn by those who denominate the diffused heat of steam latent or hidden heat, and its concentration as sensible heat. It will be seen, therefore, that it was a badly selected expression to call diffused heat latent or hidden, a description which is not applicable to the heat of steam. We do not usually call the heat of the air latent, yet it is in the ratio of the density of the air, as is familiar to all who have had experience with air pumps. For increasing density raises the heat, as when phosphorus is ignited by the increased heat of the air compressed in a small syringe. On expanding cooled air it rapidly absorbs heat from surrounding objects until an equilibrium of temperature is restored. Professor Smith, the Astronomer Royal of Scotland, has fully discussed these properties in an able paper on the cooling of air in Indian houses, and refers to the following tables of the heat of diffused and compressed air by Mr. Petrie, as entitled to confidence. Besides showing the effects of diffused and concentrated heat in a given volume of the atmosphere, they will be useful for reference.

Table No. 13, shows $508° - 60° = 448°$ below zero as the extreme ascertained cold, and $457{\cdot}2 - 60 = 397{\cdot}2$ below zero as the temperature of air expanded without receiving any additional heat to 1000 times its original volume. Table No. 14 shows $4572° + 60 = 4632°$ as the heat of air compressed to $\frac{1}{1000}$th part its original volume.

Table No. 13.

DECREASE OF THE MEASURABLE HEAT IN AIR BY DIFFUSION.

A given quantity of air expanded to vols.	Decrease of temperature from 60° Fah.	A given quantity of air expanded to vols.	Decrease in temperature from 60° Fah.
0·000	508 0	2·	104 8
1000	457·2	1·9	97·9
500	441·	1·8	90·4
200	421·	1·7	82·3
100	398·	1·6	73 7
50	370·	1·5	64·2
20	320·8	1·4	53 9
10	272·9	1·3	42·5
5	210·9	1·2	30·
3	155·2	1·1	15 9
2·5	133·7	1·0	0 0

Table No. 14.

INCREASE OF THE MEASURABLE HEAT IN AIR BY CONCENTRATION.

A given volume of air compressed to vols.	Increase of temperature above 60° Fah.	A given volume of air compressed to vols.	Increase of temperature above 60° Fah.
0 9	17·1	0·1	586·4
0·8	39·1	0·05	870·9
0·7	61·2	0·02	1363·5
0 6	91 3	0 01	1850·1
0·5	132·	0·005	2162·8
0·4	181·5	0·002	3521·0
0·3	251·	0·001	4572·0
0·2	360·7	0·000	

To apply these tables to any other initial temperature than 60°, add $\frac{1}{508}$ to the tabular number for higher, and subtract the same for every degree of lower initial temperature.

There has been and still continues to be considerable discrepencies between the quantities given of diffused heat by various Investigators. Even the latest and most elaborate experiments of Regnault and the Franklin Institute differ in their exponents of that quantity. The following are a few of these discrepancies.

TABLE No. 15.

DIFFUSED HEAT OF STEAM BY DIFFERENT AUTHORITIES.

	Fah.		Fah.
Watt	950	Thompson	1016
Black	800	Clement	990
Southern	915	Painbow	958
Rumford	1021	Regnault	880 to 973
Ure	888	Franklin Institute	996 to 1035

The smallness of the quantities operated upon, and the delicacy of the operation itself render the slightest variation much magnified when applied to larger quantities. Their general approximation is however sufficiently near for all practical purposes, and for facility in calculation, 1000° is usually taken as the diffused heat of steam of atmospheric pressure, and 212° as the boiling point, or a total heat of 1212° Fah. Now, according to the doctrine that the latent heat diminishes as the sensible heat increases, steam at 400° temperature would only have 812° latent heat, whilst steam of the temperature of 1212° would have none, but instead of proving that the heat is latent, it proves only different stages of diffusion and concentration. Regnault's experiments show that whilst the total heat of steam is not uniform, but increasing, the diffused heat becomes less and less in quantity as the spaces occupied by a given weight of steam decreases. For as the pressure is increased the extent of motion of a given quantity is decreased, from the diminished volume of steam, so that whether at high or low pressures the temperature of an atom of heat will be inversely as the space it occupies, but not hidden.

In cooling water to the unnatural liquid temperature of 5° its sudden release from that unnatural state produces excessive motion, developing 27° of heat as its measure of restorative force, which in obedience to the general laws of nature is comparatively arrested at 32°. Now, agreeably to the laws of motion the friction of a body at rest is much greater than that of the same body in motion, hence the comparative rest of water in ice requires a force of 140° of heat to give it the motion of fluidity; and the comparative rest of fluid water requires a force of 1000° of heat to give it the motion of steam. The heat therefore which moves the ice into water and the water into steam is the power externally applied to produce higher degrees of motion, and that motion will be the measure of the force so applied, just as the intensity of sound is measured by the musical scale from the number or force of the vibration of motion, as already referred to.

Generally as an effect of motion heat will be measured by the power of the particles in motion to propagate and communicate it to other particles. Unequal motion in any parts of a body would produce unequal temperature, tending however towards an equality of temperature. The power to heat a body would be as the temperature directly, and the number of atoms in motion conjointly, which would be communicated to a thermometer in contact with it, and be read off in the usual manner.

Atoms moving towards each other would unite to form a lesser number, with a greater amount of heat for each, or, if the motion tended to separate the atoms, they would be more numerous, but with less temperature for each separate atom. Thus we see the atoms combine, and uniform motion of 32° is obtained. When water becomes steam the atoms are separated with a less temperature for each, but an increasing aggregate temperature. For equal weights the heat of water would therefore exceed that of ice, and of steam that of water, as they are known to be by experiment.

It is further evident, that thermometers only measure the quantity of heat which is communicated to them, but not the space over which heat may be expanded, nor the aggregate heat contained in such space. In a large factory where a number of machines are put in motion by one engine, the aggregate power of that engine would not be indicated by the power required to move one machine, but by that power multiplied by the number of machines, and other resistances. Neither does a thermometer indicate the aggregate heat in any given space, as that depends upon both the capacity and temperature combined. It is therefore difficult to realize the idea that diffused heat can be hidden heat, and some better term of expression than latent heat should be employed, if "diffused" be not all that is necessary.

The application of the term latent to the undeveloped properties of bodies is we think equally untenable as it is to steam, and more appropriate terms should be employed if they are not sufficiently conveyed to the mind by their customary names, of air, gas, coals, water, ice, or stones. Indeed, it is satisfactory to observe the growing tendency to simplify scientific nomenclature, and the readiness with which it then passes into ordinary use, where the scientific name is most simple and expressive.

Dalton found that 1 lb. of hydrogen and 8 lbs. of oxygen burnt in a close vessel produced 9 lbs. of water, and gave out as much heat as melted 320 lbs. of ice, or 35½ lbs. of ice for each lb. of the gases; but 1 lb. of steam only melted 8·35 lbs. of ice, or less than one fourth the quantity melted by the equivalent weight of the gases. Now the thermometer does not indicate this vast difference, neither can it be the heat in the gas, since in the presence of intense cold it remains very little diminished in volume, whilst steam with very limited cold is condensed to water again. The heating power of gases is therefore like that of coals or coke, a property duly evolved under favourable combination. The light which these bodies give out may equally be designated latent, and darkness be only latent light. The sound they emit in giving forth heat and light may be equally latent. The chemical affinity, in short all the peculiar properties of bodies would thus be latent until we should cease to call them by their customary names, and only see before our eyes a mass of latents. For example, Mr. Staite has shown that heat, light, electricity, magnetism, motion and chemical affinity are all produced in one line in the voltaic pole, where the battery represents motion and affinity; electricity in the deflection of the needle; electro-magnetism in the helex: and heat and light in the ignition of the wire in irridium lamps placed in different parts of the circuit.

There is now a growing tendency to consider heat, light, electricity, and sound as phenomena of nature, intimately associated with each other, and amenable to the same general laws.

To draw general attention to the important nature of the composition of steam these remarks on the theories of heat have been made, and those who desire to extend their information on these points, will find them ably and scientifically investigated in Herepath's Treatise on Mathematical Physics, where the motive theory of heat is elaborately supported.

COKE.

Since railway acts prohibit the use of smoke from locomotives, coals can only be sparingly used, and coke is generally employed in generating steam. Important as is this portion of locomotive expenditure, it appears to have received comparatively little attention, for the ratios of quantity and heating power of coke to the coals from which it is made are much the same in 1851 as they were found to be by Smeaton nearly 130 years ago.

Had no more progress been made in making and using steam than has taken place with coke, the success of railways would have been endangered by a continuance of the coke expenditure of 1831-2-3. In the Report on Coals for the Navy, Sir H. De la Beche and Dr. Lyon Playfair state, "The whole system of manufacturing coke is at present imperfect," and condemn the management which allows some of the valuable products from the ovens to be lost; stating, as one instance of such loss, that for every 100 tons of coke made, about 6 tons of sulphate of ammonia, worth about £13 per ton., could be collected and sold. To stimulate such economy they give the following ratios of ammoniacal products in the respective coals named.

TABLE No. 16.

AMMONIACAL PRODUCTS IN COALS.

Name or Locality of Coal.	Amount of Ammonia corresponding to the Nitrogen contained in Coal.	Amount of Sulphate of Ammonia corresponding to the Nitrogen contained in coal.
Graigola	0·497	1·932
Anthracite {Jones, Aubrey, and Co. .	0·225	0·990
Oldcastle Fiery Vein .	1·590	6·175
Ward's Fiery Vein . .	1·238	4·808
Binea	1·586	6·741
Llangenock . . .	1·299	5·044
Pentripoth . . .	0·218	0·848
Pentrefellin . . .	Trace	. .
Powell's Duffryn . . .	1·76	6·835
Mynydd Newydd . .	1·808	7·310
Three-quarter Rock Vein .	1·299	5·044
Cwm Frood Rock Vein .	1·347	5·232
Cwm Nanty Gros . .	1·919	7·418
Resolven . . .	1·675	6·505
Pontypool . . .	1·639	6·364
Bedwas	1·718	6·788
Ebbw Vale . . .	2·622	10·182
Porthmawr Rock Vein .	1·554	6·033
Coleshill	1·785	6·930
Dalkeith Jewel Seam .	1·214	0·471
Dalkeith Coronation .	Trace	. .
Wallsend Elgin . .	1·712	6·647
Fordel Splint . . .	1·372	5·327
Grangemouth . . .	1·639	6·364
Broomhill . . .	2·234	8·674
Park End, Lydney . .	1·477	9·617
Slievardagh (Irish) . .	0·279	1·084
Formosa Island .	0·777	3·017
Borneo (Labuan kind) .	0·977	3·771
,, 3 feet seam . .	1 132	4·620
,, 11 ,, . .	0·813	3·158
Wylam's Patent Fuel .	2·010	7·920
Warlich's ,, . .	Trace	. .
Bell's ,, . .	0·983	3·818

Besides these products there are also much heat and much hydrogen gas evolved during coking, which are seldom turned to any profitable account. Of late years several iron works employ the escaping gases from their furnaces with economical results, and at Dundyayvan Iron Works Mr. Budd states the saving to be at least 8 per cent. In cooling coke in the ovens there is also a considerable quantity of pure hydrogen produced from the decomposition of the water by the intense heat of the oven. It is at least worth a trial to determine the commercial value of collecting such products of the coke furnace, for what iron companies do railway companies could also do, and improve upon.

The best process of manufacturing coke is still also an open question, some engineers preferring *hard*, others *soft* burnt coke, but the preponderance of numbers is in favour of the hard coke. Our observations tend to a different result, and to induce more attention to the manufacture of coke, the following remarks are submitted, accompanied by an abstract of the three valuable reports by Sir H. De La Beche and Dr. Lyon Playfair, on coals for the steam navy.

The comparative term *hard* is understood to apply to coke from which all volatile matters have been expelled, and the term *soft* to refer to coke, in which a portion of these gases still remain. They apply equally to the same vertical piece of coke in the oven as to different processes of coking. The upper part would be comparatively hard, and further heat would have little to expel from it, whilst the lower part near the bed of the oven would be *softer*, and evolve a gaseous flame, by being exposed to further heat.

In the Crystal Palace may be seen some beautiful specimens of hard coke, clean, silvery-looking columnar pieces. At the base of these same pieces may be observed a darker looking portion, of less pleasing appearance than the top portion. This darker or comparatively softer part we regard as the most economical generator of steam in locomotive furnaces, arising from its still retaining a portion of the original gases in the coals. That hydrogen gas is more valuable in generating steam than has usually been estimated, will be shown from practical examples with coals at the Par Consols mine, where they *water* their open burning coals to give *intensity* of heat in the furnace. Many of the best locomotive drivers *water* their coke to make it "*last longer*;" and a recent patent in America is for employing steam properly distributed over the fire to promote economy of fuel. In each case it only introduces water in a finely divided state into an intensely hot fire, which decomposes it into its equivalent of hydrogen and oxygen, and thus aids the evaporative powers of the fuel. From the coking property of some coals, water could not be beneficially used with them for steaming, since it would increase the tendency to coke, and retard the generation of steam by presenting to the boiler a fire surface comparatively cold to that presented by the glowing intensity of open burning coals. This difference may be observed in a common house fire, when the poker is required to break the surface to obtain greater heat, whilst with other coals no such coking occurs, or "pokering" the fire is required. The blacksmith's forge is an every-day instance of wetted coals producing a very superior fire to coals in their ordinary state where intensity of heat is required in the centre of the fire, and not to radiate externally against a boiler or other object. Whatever evaporative benefit may be derived from such introduction of water will arise, it is evident, from the gases evolved, and shows how very desirable it is that, as far as practical, coking should aim at retaining and not expelling such gases.

We are aware that it is usually held that the portion of water in coals, varying from 1 to 2 per cent., and that absorbed by coke, varying from 1 to 7 per cent. is not only a loss of weight, but also requires part of the remaining fuel to evaporate such water. That it would be injudicious to purchase wet fuel—also that such wetted fuel might sensibly retard the lighting of a fire, is evident; but it is also evident that if a small per-centage of water can be converted into hydrogen and oxygen, they will be more valuable than an equal weight of either coals or coke; for in coke they would partly re-supply the gases expelled during the process of making, and add to those in coals, thus fairly accounting for the benefit said to be obtained in practice.

Unless urged by a strong draught, nearly all the forms of pure carbon burn badly. The diamond long resisted the action of heat until Lavoisier succeeded in fusing it, and showed it to be pure carbon.

Coke also requires a strong draught to promote its combustion. Lamp black in certain states ignites spontaneously in casks, but even on being exposed to the air it presents only the appearance of a number of minute sparks, with little heat and no flame. The least admission of air to spontaneously ignited coals, however, produces immediate conflagration, not unfrequently leading to serious consequences. Now, if the process of coking could be so far perfected as to retain a considerable portion of these combustible qualities of coals, and only expel the carbonaceous smoky portion, the economy would be obvious. Peat has frequently been suggested as a fuel for locomotives, and about 11 or 12 years ago Lord Willoughby D'Eresby, so well known for his promotion of industrial experiments, had some peat tried in the Hesperus locomotive, on the Great Western Railway. This engine was of Hawthorn's patent return-tube construction, and required about one third more peat than coke with equal draughts. This peat, however, did not appear at all equal in quality to the best hard black peat of the border districts of England and Scotland, being more like that brown turf cut immediately below the surface of some deep mosses; for peat, like coals, varies in lighting and heating properties. Mr. Vignoles has also interested himself in the same field, and the peat companies now forming are also directing their attention to the various chemical and useful properties of peat and peat charcoal for heating purposes, with what results remains to be decided, as opinions are divided on its economical merits.

The gauge contest, which so rapidly promoted locomotion, also afforded some information on the economy of hard and soft coke.

During the trials of locomotive engines under the sanction of the Gauge Commissioners, the rival interests of powerful companies were brought into action, and the least point of seeming advantage of load, gradient, wind, or coke was carefully noted on both sides.

The Newcastle or Durham coke principally used on the northern railways bore a high name for its evaporative powers and durability, whilst the Welsh coke used on the Great Western Railway had only a local character inferior to the northern coke, and a claim was made for an equivalent allowance for this supposed difference.

After these trials were over the question was practically tested in the broad-gauge engines, ending contrary to anticipation in favour of the softer Welsh coke, as regarded *time* and *load*, with draughts suited to each variety. It was found that the blast pipe used for Welsh coke was too large, and the draught too little for the Newcastle coke, and the engines failed to keep time until the blast pipe was made less. This of course increased the draught and promoted the combustion of the coke, but it introduced the greater evil of increased resisting pressure against the acting pressure on the piston, leaving a balance in favour of the Welsh coke for equal loads at equal velocities by equal quantities of coke. Of the Welsh coke, the softer burnt was likewise found the best, and produced the best results in a locomotive boiler. An annoying instance of this occurred when the power of a particular engine was to be tried. The more beautiful looking upper parts of the coke were selected to fill the tender, and the trial proved a failure for want of steam. The rejected portion of the coke, supplied to an engine for ordinary duty, produced a contrary result.

In Lancashire again, a contrary opinion was arrived at, and the inability of coke to resist the action of a hard-coke blast was assigned as a reason for its inferiority to harder coke, although it is clear that if this coke could have generated even less steam with a larger blast pipe than the hard-coke with a small one, the effective power of the engine to draw a load might still have been equal. For every pound of resisting pressure taken away gives more than a corresponding advantage to the acting pressure, since there is less steam to escape for an equal amount of tractive power given out; hence, with the present construction of locomotives, it is always a desideratum to use the largest possible blast pipe. The harder the coke, the more is such an object frustrated. Coke, like coals, varies considerably in its heating powers, requiring the draught and process of combustion to be carefully attended to for each, so as to evolve the best results. Mr. Wood states, that, as compared to the Hutton and Worsley cokes taken as 100, the practical values of six other varieties not named were respectively, 76·3, 80·3, 81·7, 89, 90, 90·1, as tried, it would appear, under similar circumstances, which however might not be a fair trial for the peculiarities of each coke, since the tenderness above referred to was stated as one cause of inferiority. The coke column in the annexed tables will show the per-centage of hard coke in different coals as determined by careful experiments.

The proper regulation of the blast to the coke employed is very essential to economy. To produce the chemical equivalent of perfect combustion it requires by weight about 2·66 lb. of oxygen for each pound of carbon. Since $\frac{4}{5}$ of the air is nitrogen it requires 60 cubic feet of air to produce 1 lb. of oxygen; therefore an engine consuming coke equal to 25 lb. of carbon per mile would require $25 \times 2·66 \times 60 = 3990$ cubic feet of air to pass through the furnace during the time of running one mile. It is this vast quantity of air required which renders the blast-pipe necessary, though it absorbs power varying at high velocities from 25 to 30 per cent. of the working power of the steam. A larger supply of air is, however, required practically to meet the loss from various causes. It is stated that during the steam-coal investigation no combustible gases escaped up the chimney, but, on the contrary, much free oxygen, rather a singular result.

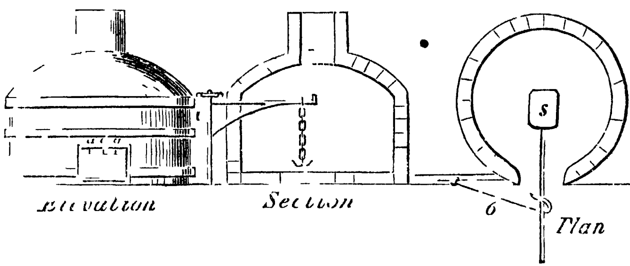
This experimental boiler had a "split" flue, a class which has usually an "eddy" favourable to the retention of the cold air or gases, and air admitted at the back of the grate might thus pass away uncombined, and form a portion of the gases ascending in concentric or other separate circles of their own. There is however, this difficulty; if the combustion was perfect the absorption was less perfect by 20 per cent. than a larger boiler of the same class at the Par Consols mine.

Be this, however, as it may with stationary boilers set with split flues, in locomotive boilers there is evidently much combustible gas passing off, since it readily ignites either in the smoke-box, or at the top of the chimney when air is supplied. To economize the consumption of these escaping gases Mr. Deurance introduced a gas fire-box between the coke fire-box and the tubes, making a double fire-box, like those used also for coke. A series of short tubes communicated from the coke to the gas fire-box through the divisional water space, and the admission of air was regulated by valves under the control of the driver. This was, with considerable success, tried for eleven months on the Grand Junction Railway both with coke and coals mixed, and separately. The cost was from *5d.* to *6d.* per mile, including all repairs for the regular passenger traffic, of which particulars will be given in their place. Even without such a plan benefit is found to arise from admitting air occasionally by the fire-door according to the state of the fire and the height of the door from the level of the fire surface, but uniform admission is detrimental, and therefore it requires to be carefully regulated to produce perfect combustion.

Coke Ovens.

Like charcoal, coke was formerly made in heaps roughly covered from the air, but furnaces or ovens are now employed for that purpose. These ovens are of various forms, but it is not so much the form as the proper admission of air to the coking coals which is of importance. With a well-regulated supply of air there is not found to be any marked superiority in the most costly ovens over the cheaply constructed circular oven of which Figs. Nos. 11, 12, 13, show an elevation section,

FIG. No. 11. FIG. No. 12. FIG. No. 13.



Circular Coke Oven.

and plan. They usually hold about five or six tons of coals, and the air is admitted by the doorway at *a a a*, which is finally closed as required and luted with clay. When the process of coking is completed the brick-built door is taken down and water injected into the oven to cool down the coke. On this being done, the coke is removed by the crane C, and the large iron shovel *s*, from the oven, which is then ready to be filled again. A number of these ovens may be erected in one cluster, and connected with a central chimney, as is done by Messrs. Cory, New Barge Wharf, London.

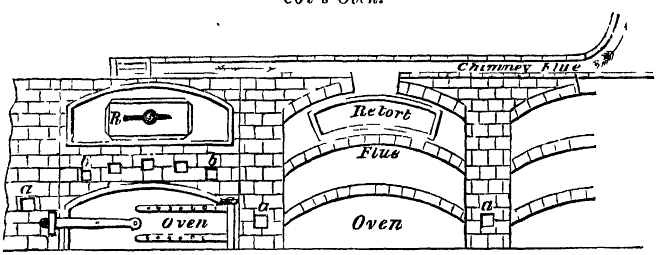
Church's circular ovens were on the same general plan, but with a series of air passages below the coke bed, but not in contact with the coke. When the coking process was complete these passages were opened, to admit a current of cold air to aid in cooling down the hot coke, which was effected by carefully excluding all air from the oven without the use of water. Coke so made was therefore perfectly dry and free from hygrometric water (until it absorbed it from the atmosphere), and enjoyed considerable repute for its steaming power.

The plan of cooling with water is now generally preferred, and when done in the oven there is a better return of large coke than when drawn out hot and cooled outside the oven.

Cox's patent oven is arranged to make both coke and gas at one time, as seen in Fig. No. 14.

FIG. No. 14.

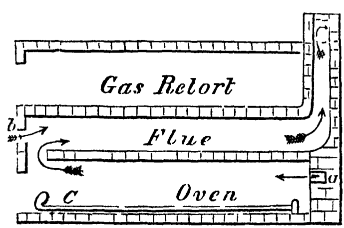
Cox's Oven.



Elevation Section.

In this oven the air is admitted by the side passages *a a*, passing along the brick work and opening into the back of the oven, as seen in Fig. No. 15. By this arrangement the air is

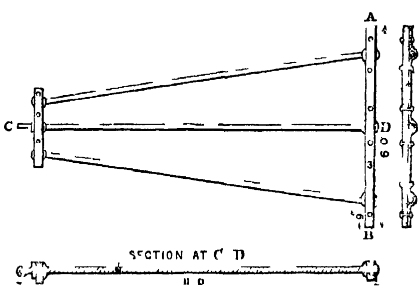
FIG. No. 15.



Longitudinal Section.

heated before it comes near the coking coal, and passes by the flue to the chimney, as seen by the arrows. When gas is required a retort R is placed in the upper arch, which is acted upon by the escaping heat of the oven. For coke alone the upper arches might be dispensed with, and the chimney placed at the front instead of the back, which would reduce the cost of erection without impairing the quality of the coke. *b b* are eye holes for observing the process of coking by the escaping products of combustion, and also for admitting air to promote the draught, as may be required. The coke is drawn out hot on the "Cradle" C., Figs. No. 16, 17, which show the

Figs. 16 and 17.

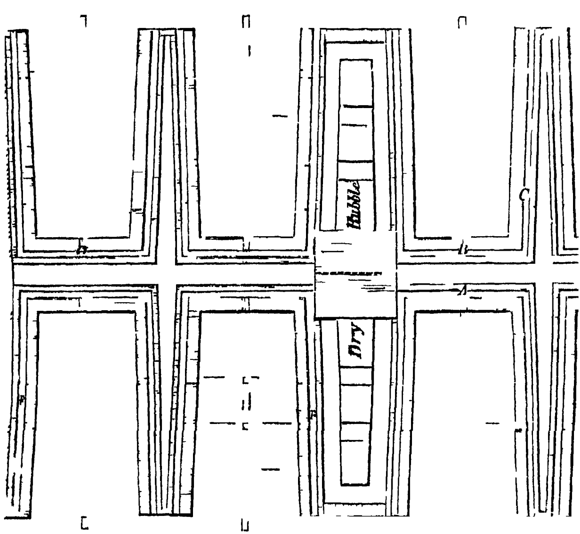


plan and edge view of this implement. It is placed on the floor of the oven, as seen in Fig. 15, and the coals put in the oven afterwards. When the coking is completed the door is opened, and a strong chain from a crab is attached to the hook of the cradle, and by the exertion of two or three men working the crab, the whole mass is drawn at once from the oven hot, and cooled with water afterwards. The coke being more friable when hot than when cold, there is rather more small coke by this plan, than by cooling in the oven

Amongst the most recently constructed coke ovens are those of the Bristol and Exeter Railway at Bridgewater In them is embraced the principal improvements of late years, with modifications of both Church's and Cox's patent ovens Church's cooling air passages are made to come in contact with the coke, to promote equal ignition, and the side air passages have frequent openings into the oven, whilst the upper passages further regulate the admission of air, as fully illustrated in the following drawings from the "Aide Memoire of Military Sciences"

FIG No 18

Coke Oven

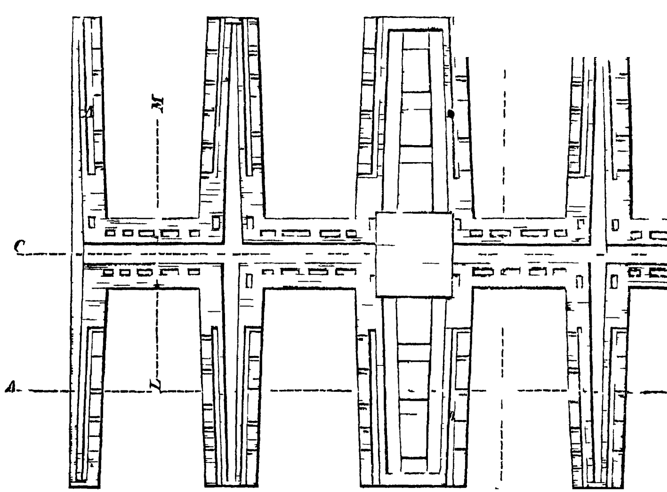


Ground or Floor Plan

Fig. No. 18, is a ground plan of 8 coke ovens, communicating with a central chimney, showing the lowest side-air passages leading from the front, and by the transverse dotted passages underneath the coals to promote equal ignition of the whole mass at once. When this is done these passages are closed for that occasion.

FIG. No. 19.

Coke Oven.

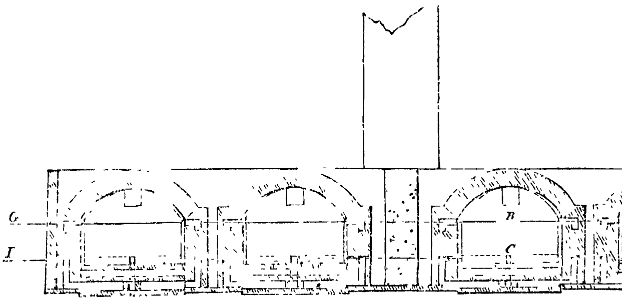


Plan at Air Passage.

Fig. No. 19, is a plan at the upper air passages for regulating the supply to the burning fuel. The side openings introduce the air so as to distribute it as equally as possible above the burning mass. The spaces parallel with the chimney between the ovens are filled up with dry rubble, as shown in both plans.

FIG. No. 20.

Coke Oven.

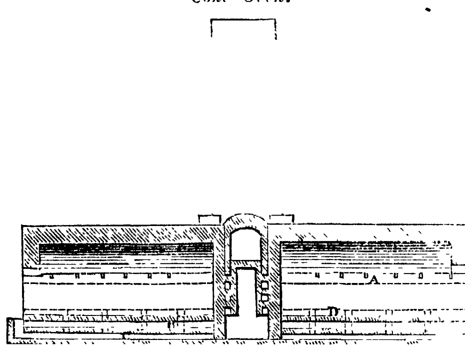


Transverse Section at A B, Fig. 19.

Fig. No. 20 is a section, at A B of Fig. 19, showing the vertical construction of the ovens, air passages, side openings, lowest air passages, and central openings, leading into the flue which connects them with the chimney.

FIG. No. 21.

Coke Oven.

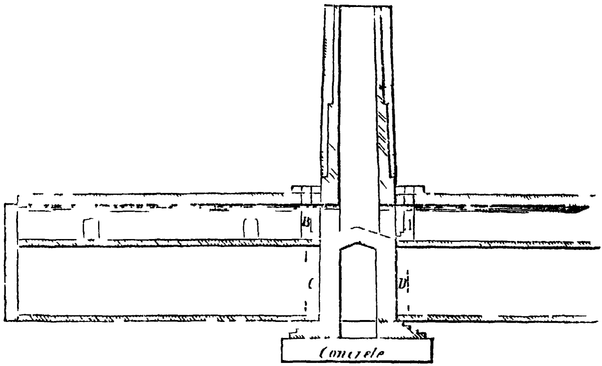


Longitudinal Section at E F, Fig. 19.

Fig. No. 21, is a section of two ovens at E F, Fig. 19, showing the longitudinal plan of the ovens and air passages, with the manner of their junction at the back.

FIG. No. 22.

Coke Oven.

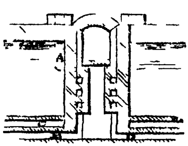


Longitudinal Section of Oven and Chimney Flues.

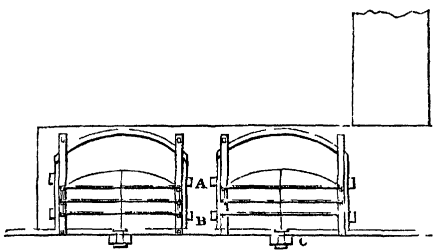
Fig. No. 22, is a longitudinal section of the oven and chimney-flue, with the dampers A B.

FIG. No. 23. FIG. No. 24.

Coke Oven.



Vertical Section at the Junction with the Chimney.



Elevation.

Fig. No. 23, is a section between the ovens at C D, showing their connection with the chimney.

Fig. No. 21, is a front elevation of two ovens, showing the external air orifices A B, with the form of the cast-iron doors and fittings.

The process of making coke with all these ovens, is to fill them with their respective quantities of coals in such rotation as to produce a daily supply of coke. When the coke is cooled in the oven, the coals require to be lighted, but when the coke is drawn out hot, the coals then put in ignite readily by the heat of the oven. The door is then lined inside with fire bricks, and closed and luted with fire clay, to make it air-tight. Sometimes no door is used, and the opening is built up with fire bricks, leaving regulating air passages to be closed as the coking progresses. The duration of the process is from 48 to 96 hours, but is a good deal dependent on the composition of the coals, the state of the atmosphere, and the class of oven employed. When coals contain little or scarcely any sulphur, the process is slow, although an excess of sulphur is injurious to coke, and electricity has been employed to remove it before the coke was withdrawn from the oven. Still a certain amount of sulphur promotes combustion, and in this respect the Rhonda Valley coal of South Wales makes better coke than the Newport coals, which, from containing more sulphur, make superior household coals.

It is the duty of the coke burner to watch the progress of the combustion by the eye-holes for that purpose, and to regulate the admission of air accordingly. When scarcely any flame can be observed to pass from the heated mass of fuel the air is altogether excluded for some time before the oven is ready to be "drawn," or "cooled," as the case may be.

Since, therefore, even with the most carefully arranged air passages, much depends upon the care of the burner, there exists, as previously remarked, an opinion amongst experienced men that with such care judiciously exercised, the cheaper class of ovens are nearly as good as the most expensive ones for all practical purposes. The Great Western Railway Company have both classes of ovens, and find no material difference in the products, either in quantity or in quality.

The Bristol and Exeter ovens yield about 13 cwt. of good coke, 6½ cwt. of small and waste coke, and some ashes, fit for lime burners, from a ton of Cardiff coals. The coke is drawn out of the ovens hot, by a cradle similar to Cox's, Figs. Nos.

16, 17, which probably increases the comparative quantity of small to large coke.

The superior economy of coals for generating steam has led to several trials to effect that object, without evolving smoke. Gray and Chanter have each especially designed fire-boxes for this purpose, and Durance has also tried it in his gas fire-box referred to. Whilst therefore ingenuity continues to be directed to obtain this object, there is no reason to doubt its ultimate success, when coals either in union with coke or not may be profitably employed in railway engines. From the high ratio of carbon in anthracite, and its almost smokeless combustion, it would appear well suited for locomotive purposes, more especially as it also combines combustible gases, and requires a draught similar to coke. The following abstract of the properties of various coals and anthracite will therefore supply desirable information to the locomotive as well as to the marine engineer on these essential points in the economy of steam power.

COALS.

The preceding remarks on heat, combustion, and coke, will be rendered practically available in selecting coals for particular purposes, by the following tabular arrangement of 37 varieties of Welsh, 19 of Newcastle, 28 of Lancashire, 8 of Scotch, 1 of Irish, 8 of Derbyshire, 9 of Van Diemen's Land, 2 of Patagonian, 3 of Bornean, 6 of Chilian, 5 from different localities, and 42 of American coals, with 6 of patent fuels. With the exception of the American varieties, the 132 other varieties are abstracted from the able reports of Sir H. De la Beche, F.R.S., and Dr Lyon Playfair, F.R.S., "On Coals suited to Steam Navy," begun in 1846, and the last report issued in April, 1851. The American government had instituted a similar inquiry into coals, and a copy of their report coming into the hands of Mr. Hume, M.P., that able public man lost no time in forwarding it to the Lords of the Admiralty, (10th June, 1845,) suggesting that a similar course should be pursued to ascertain "the best coals for the naval steamers of this country." This was promptly undertaken by the Admiralty, who on the 28th June issued instructions to ascertain how the "inquiry could be conducted with the greatest effect." To the able manner in which this investigation has been conducted in all its details, and to the lucid arrangements of the reports themselves, we are indebted for this valuable addition to our knowledge of the properties of coals generally.

In endeavouring to compress the lengthened remarks on the combustible peculiarities into a tabular form, the leading features only have been given, and there was some difficulty to convey a brief yet fair impression of the text. It has however been attempted, with every desire to do impartial justice in a matter so important to the public, and to each coal-mine proprietor.

The properties sought to be determined by these experiments were, briefly, 1st. Evaporative value; 2nd. Mechanical structure; 3rd. Combustible character; and 4th. Chemical composition.

Evaporative Value.

To Smeaton we believe is due the merit of the first systematic attempt to define the comparative effect of different coals. In 1769 he constructed an experimental engine, having a cylinder nearly 10 inches diameter and 3 feet stroke. The boiler consumed 55 lbs. of coals per hour, and evaporated 6·14 lbs. of water under a pressure of 7·8 lbs. per square inch for each pound of coals.

Taking the Halston coals from Yorkshire as evolving an evaporative power of 100, he found the useful ratio of the others used by him as under—

Halston . .	100	Welsh . . .	110
Berwick Moor . .	86	Newcastle . .	120
Middleton . .	110	Cannel . . .	130

Coke $\frac{4}{3}$ of that of the coal it was made from.

The quantity of coke to coals he found about 66 per cent., or nearly the same as at present. Although recent investigations have placed the Welsh coals at the top of the practical evaporative test, yet these early experiments bear ample evidence of the care with which they had been made. Under his best boilers Smeaton found 7·88 lbs. of water by 1 lb. of coals, from 212°, as the evaporative value of Newcastle coals. Watt's improved boiler gave 8·62 lbs., and this was long considered the standard till the Cornish engineers gradually increased it to 10·74 lbs. in 1840, and in 1846 to 12·89 lbs. of water evaporated by 1 lb. of coals.

Dr. Ure gives the heating power of 1 lb. avoirdupois of different fuels as under—

1 lb. of	Heats water from 52° to 212°	Evaporates water from 212°	Weight of air to burn 1 lb. of the fuel.
	lbs.	lbs.	lbs.
Dry wood . .	35	6·36	5·96
Ordinary wood .	26	4·72	4·47
Wood charcoal .	73	13·27	11·46
Coal . . .	60	10·90	9·26
Coke . .	65	*18·88	11·46
Peat charcoal .	64	18·63	9·86
Peat . . .	30	5·45	4·60
Hydrogen gas .	76	13·81	14·58
Oil . . .	78	14·18	15·00
Wax	78	14·18	15·0
Tallow . .	78	14·18	15·0
Common alcohol .	52·6	9·56	11·6

Mr. Wicksted gives the following comparative ratios of practical or realized evaporation and prices at London Bridge. The latter now requires modification, to the extent seen in the last column.

Name of Fuel.	Water evaporated from 52° by 1 lb. of fuel.	Cost per ton at London Bridge.		Sept. 1851.	
	lbs.	*s.*	*d.*	*s*	*d.*
Welsh, best	9·493	17	11	21	0
Anthracite	9·014	17	0	21	0
Newcastle, best small . . .	8·524	16	1	16	6
,, average . . .	8·074	15	2¾	14	9
Welsh, average	8·045	15	2¼	20	0
Gas Coke	7·908	14	11	14	4
Half coke and half Newcastle small	·7·897	14	10¼	14	0
Half Welsh and half Newcastle .	7·865	14	10	17	10
Half Newcastle and half Derbyshire	7·710	14	6½	13	9
Newcastle, average of large . .	7·658	14	5½	15	8
Derbyshire	6·772	12	9¼	12	9
Blythe Main Northumberland .	6·600	12	5½		

The value given here for anthracite, is, however, much less than that found by Messrs. Josiah Parkes, and Charles Manby, of the Institution of Civil Engineers, in 1840, from a series of experiments made on anthracite as a steam fuel. With a boiler, having 340 square feet of heating surface the result gave 13·48 lbs. of water as the evaporative value of 1 lb. of the fuel, compared with 11·89 lbs, the then highest recorded duty of a Cornish boiler, having 961 square feet of heating surface, or 13 per cent. in favour of the anthracite with a small boiler. What the difference would have been in boilers of equal heating areas they had not the means to decide, but considered 13 per cent. as the minimum difference of value between anthracite and the best Welsh coals.

The subject was one of growing importance, and under the sanction of the Government, it has now been ably investigated in the following manner.

The evaporative value was arrived at by taking the mean of three separate days' trials with each fuel in a small Cornish boiler 12 ft. long, 4 ft. diameter, with inside flue of 2 ft. 6 in.

diameter and flat ends. The fire was placed in one end of this flue, and the current of heated gases returned by "split" flues round each side of the boiler to the front, where they united and passed under the boiler to the chimney. During two of the trials the pressure on the safety valves was 1 lb. per square inch, and usually 3 lbs. during the third trial.

As the comparative weight to bulk of water varies with its temperature, the necessary corrections were made by the following table, which shows a difference of 85·6 lbs. between the temperature of 70° and 212° in the actual quantity of water in the boiler.

TABLE No. 17.

Temperature of Water, Fahrenheit.	Ratio of apparent to real Weight.	Actual Weight of Water in Boiler when filled to Normal Point.	Difference between actual and apparent Weight.
°		lbs.	
70	1·0000	4730·000	0·000
80	0·9996	4728·108	1·892
90	0·9992	4726·216	3·784
100	0·9987	4723·950	6·050
110	0·9983	4721·960	8·040
120	0·9979	4719·097	10·903
130	0·9974	4717·795	12·205
140	0·9971	4715·283	14·717
150	0·9967	4714·012	15·988
160	0·9954	4708·242	21·758
170	0·9940	4701·620	28·380
180	0·9923	4693·579	36·421
190	0·9901	4683·173	46·827
200	0·9879	4672·767	57·233
202	0·9869	4668·037	61·963
204	0·9859	4663·307	66·693
206	0·9849	4658·577	71·423
208	0·9839	4653·847	76·153
210	0·9829	4649·117	80·883
212	0·9819	4644·387	85·613

The heating effect of the wood used to light the fires was first experimentally determined, and its effect,—ascertained each trial by the following table based on Regnault's experiment,—was deducted from the total evaporation of both wood and coals.

TABLE No. 18.

SPECIFIC AND DIFFUSED HEAT OF WATER AND STEAM FROM 32° TO 446° FAHR.

Air Ther. Cent.	Mercurial Cent.	Number of Unities of Heat abandoned by one kilo. of water in descending from T to 0°	Air Ther. Fah.	Mercurial Fah.	Number of Unities of Heat contained in one pound of water at T°.	Mean specific Heat of Water between 0° and T cent. or between 32° and T Fah.	Specific Heat of Water from T to T + dT.	Latent Heat of Steam saturated to the temperature T. Cent.	Fah.
°	°		°	°					
0	..	0·000	32	..	32·000	..	1·0000	606·5	1091·7
10	..	10·002	50	..	50·003	1·0002	1·0005	599·5	1079·1
20	..	20·010	68	..	68·018	1·0005	1·0012	592·6	1066·7
30	..	39·026	86	..	86·016	1·0009	1·0020	585·7	1054·2
40	..	40·051	104	..	104·091	1·0013	1·0030	578·7	1041·6
50	50·2	50·087	122	122·36	122·156	1·0017	1·0042	571·6	1028·9
60	..	60·137	140	..	140·246	1·0023	1·0056	564·7	1016·4
70	..	70·210	158	..	158·381	1·0030	1·0072	557·6	1003·7
80	..	80·282	176	..	176·507	1·0035	1·0089	550·6	991·1
90	..	90·381	194	..	194·685	1·0042	1·0109	543·5	978·3
100	100·0	100·500	212	212·0	212·900	1·0050	1·0130	536·5	965·7
110	..	110·641	230	..	231·153	1·0058	1·0153	529·4	952·9
120	..	120·806	218	..	249·450	1·0067	1·0177	522·3	940·1
130	..	130·997	266	..	267·794	1·0076	1·0204	515·1	927·2
140	..	141·215	284	..	286·187	1·0087	1·0232	508·0	914·1
150	150·0	151·462	302	302·0	304·623	1·0097	1·0262	500·7	901·2
160	..	161·741	320	..	323·133	1·0109	1·0291	493·6	888·5
170	..	172·052	338	..	341·693	1·0121	1·0328	486·2	875·1
180	..	182·398	356	..	360·316	1·0133	1·0364	479·0	862·2
190	..	192·779	371	..	379·002	1·0146	1·0401	471·6	848·9
200	200·0	203·200	392	392·0	397·760	1·0160	1.0410	464·3	835·7
210	..	213·660	410	..	416·588	1·0174	1·0481	456·8	822·2
220	..	224·162	428	..	435·480	1·0189	1·0524	449·4	808·9
230	..	234·708	446	..	454·474	1·0204	1·0568	441·9	795·4

The correction for variation of temperature of the feed-water was made by the following tabular ratios.

TABLE No. 19.

Temperature. Fah.	Actual weight of an Unity of Water.	Temperature. Fah.	Actual weight of an Unity of Water.
°		°	
40	1·001464	62	1·000712
42	1·001451	64	1·000534
44	1·001439	66	1·000356
46	1·001426	68	1·000178
48	1·001414	70	7 000000
50	1·001401	72	·999763
52	1·001294	74	·999527
54	1·001196	76	·999290
56	1·001094	78	·999054
58	1·000992	80	·998818
60	1·000890		

C ›mparative Evaporation of different Boilers.

To determine how far the experimental boiler gave results as compared with the best Cornish boilers, Mr. Phillips went to the Par Consols mine and had 119,700 lbs. of water evaporated from 92° by 11,730 lbs. of coals, equal to 10·204 lbs. of water by 1 lb. of coals, or 11,428 lbs. from 212°.

The Mynydd Newydd experimental coals had the nearest chemical composition to those used in the above trial, and only evaporated 9·52 lbs. of water per lb. of coals from the experimental boiler, being very nearly 20 per cent. less than in the larger boilers. The ratios therefore of realized evaporation in the tables multiplied by 1·1995 will give the value for boilers of the same evaporating power as those at the Par Consols mine.

From this it will be noticed that the tabulated evaporative results are only comparative, under the same boiler and conditions, for the precise value would vary according to the merits of the particular boiler employed.

Coking Quality of Coals.

The quantity of coke in the several varieties was ascertained by subjecting a portion of them in a crucible to a white heat for several hours, and weighing the coke left in the crucible.

This useful column in the tables will be a new source of information for the selection of particular coals for coking purposes. During the experiments only one sample of locomotive coke was sent for investigation. This was made by Messrs. Cory, of New Barge Wharf, Lambeth, from Andrews's House Tanfield coals, in a plain circular oven, having a brick-built door, and the coke cooled with water in the oven, yielding about 65 per cent. of coke from the coals used. To test the practical with the theoretical effects of coking, three separate trials were made in the crucible on coals from the same mine, which gave a mean of 65·13 per cent. of coke to coals, and was regarded as satisfactory evidence of the practical return of coke by Messrs. Cory's process of producing hard coke. Although in coking the weight of the fuel decreases 35 per cent. the bulk appears to gain about 11·7 per cent. as seen in the table. In one trial under the experimental boiler with the draught increased by blowing the steam into the chimney, the coke evaporated about 20 per cent. less water for equal weights than the coals it was made from. The same increased blast was used both with the coke and coal to give comparative results, and the following statement of this trial will show the precautions taken to ensure accuracy with all the experiments.

TABLE No. 20.

COMPARATIVE EVAPORATION OF WATER BY COALS AND COKE UNDER THE SAME CONDITIONS.

Particulars.	Coals.	Coke.
Fire lighted	10 h. 0 m.	9 h. 0 m.
Steam up	11 h. 0 m.	10 h. 15 m.

Particulars.	Coals.	Coke.
Wood used	10 lbs.	10 lbs.
Initial temperature of water in boiler	192°	203°
Temperature of water in tank	50° mean	50° mean
Barometer	29·7 mean	29·65 mean
Extremes of external thermometer	32°—56°	36°—56°
Extremes of internal thermometer	58°—68°	52°—65°
Dew point	48° mean	461 mean
Area of damper open	168 in.	168 in.
Fuel consumed	2119 lbs.	2184 lbs.
Ashes left	41 lbs.	94 lbs.
Combustible matter in ashes in general from about 20 to 70 per cent. averaging about 38 per cent.		
Cinder left	12 lbs.	none
Combustible matter in cinder in gèneral, from about 20 to 80 per cent. averaging about 55 per cent.		
Clinker	42 lbs.	25 lbs.
Average soot in flues	none	none
Combustible matter in soot in general, from about 55 to even 90 per cent. averaging about 70 per cent.		
Water evaporated	17895 lbs.	15275 lbs.
Water evaporated from 212° by 1 lb.	9·91 lbs.	7·91 lbs.
Burnt per hour per square foot of grate	12·4 lbs.	12·81 lbs.
Duration of Experiment	31 h.	34 hours
Specific gravity	1·264	
Mean weight of 1 cubic foot	52·1	30·
Economic weight per 1 ton	42·99	74·66
Cohesive power		
Pressure of steam blowing off	3 lbs.	3 lbs.
Evaporation per hour	526·3 lbs.	449·2 lbs.
Fuel per hour	62·3 lbs.	66·2 lbs.

* The per-centage of combustible matter in the ashes, cinders, and soot, is not from these experiments, but an average for general reference.

From this table it is seen that 1 lb. of coals evaporated 9·91 lbs. of water and 1 lb. of coke only 7·91 lbs. or 20·1 per cent. less than the coals. The quantity evaporated in a given time was also greater by 77 lbs. per hour for the coals, amounting to 2620 lbs. of water in the 34 hours' trial.

The increased draught also increased the evaporative results of the coals $5\frac{1}{2}$ per cent. over the previous trial with the ordinary flue draughts only. The evaporative-*power* column includes the estimated loss from the unconsumed combustible matter in the residue. The *realized* column is what was actually obtained during the trials.

Smeaton, it has been remarked, found a loss of $\frac{1}{6}$ of steam-generating power from coke, or 16·7 per cent. and 31 per cent. of loss in the manufacture, being a near approximation to the data found from these experiments.

Mechanical Structure.

The general appearance of the coal was noted, and its comparative bulk to weight for stowage was ascertained by filling a box of 6 cubic feet capacity, with each variety tried, and carefully noting the weight per cubic feet. This weight multiplied by the realized ratio of evaporation per lb. gives the evaporative power in 1 cubic foot of the particular coals.

The cohesive property was found by placing 100 lbs. of suitable sized firing pieces which would not pass through a sieve of 1-inch mesh, in a vertical wooden cylinder, 3 feet diameter and 4 feet high. This cylinder had internal angular shelves, which on its being turned round on its axes, carried the coals upwards and let them fall to the bottom, which more or less broke them according to their natural cohesion. Each variety was subjected to two trials of 50 revolutions each time, and then the mean number of pounds of coals which would not pass through the 1-inch mesh sieve is given in the tables as the comparative cohesion per cent. to resist ordinary attrition.

The ordinary hygrometric water in coals was determined by drying them at a temperature of 212°, and has been placed under this heading as more allied thereto than to chemical union, that more extended observation on the effect of such water from fuel on the practical results might be noticed.

Combustible Character.

The combustible peculiarities were noted from observation and analyzation of the residue arising from combustion. The ease or difficulty of lighting, the draught best suited, the rapid or slow combustion, the coking or open burning, the amount of attention from the stoker, the quantity of smoke, ashes, cinders, and clinkers, with the ratios of unconsumed combustible matter in the residue were all noted.

Of the residue, the whole per-centage is given, and the clinkers separately. Ashes are no doubt troublesome when in large quantities, but these may be approximately ascertained by the chemical analysis. Clinkers are, however, more troublesome, and fusible ones which adhere to the fire bars particularly so in obstructing the draught. In the table these are marked ad. for adhesive. In locomotive furnaces the formation of clinkers is very prejudicial to the generation of steam, and Goldsworthy Gurney, Esq., from his unpleasant experience of these effects on his common-road steam carriages, calls them "fire eaters." He mentions an experiment made by himself and Sir George Cayley, Bart., to test the effect of clinkers in retarding the generation of steam. They introduced a little lime to hasten the formation of the clinker, which soon exhibited greater effects than was anticipated, rendering it difficult to keep up the steam.

The per-centage of combustible matter in the residue varies in proportion to the quantity of small coals which falls through the grate, and generally the increase of a per-centage of residue would indicate an increased per-centage of combustible matter also, over the per-centage when the fuel was fairly consumed, and the residual matter comparatively small.

It will be noticed that the Newcastle coals so generally employed for domestic use in London are of a caking, smoky character, which, however suitable the caking is for the house or forge fire, is not so suitable for steam furnaces. It might be worth a fair trial to ascertain whether keeping the open-burning Welsh household coals *in water* would impart that coking quality to them in the house fire which it does in forge operations, as their cleanly smokeless character and superior heating power are far more than compensation for the more easily ignited bituminous coals.

An experiment with 7 lbs. of Pyle coals in their ordinary state, and 7 lbs. wet with water, showed a decided difference on a common house fire in coking in favour of the wet coals, but was found to operate the reverse way in evaporating water, for the dry coals kept a more open fire, and evaporated 2 lbs. more water in 6 hours. A further experiment by immersing 20 lbs. of these coals in water for 24 hours showed that they absorbed no appreciable quantity of water, but that due to their wet surfaces, and when these were dry no perceptible difference in weight was detected.

Chemical Composition.

The chemical analysis was carefully made from a fair average sample of the coals as mined, checked by an analysis of pure coal from the same sample. Coals in their ordinary state contain more or less shaly, whitish, dull blackish, extraneous matter or veins of iron pyrites, besides the pure coals, which decrease the evaporative value whilst they increase the duty of the stoker and per-centage of residual matter. An analysis therefore of the pure coal, or even the specific gravity of the pure coal would be no just criterion of the practical composition or practical weight per cubic foot. The analysis therefore of the average sample only *as mined* is given under this heading, as the weight per cubic foot was given under the heading of mechanical structure.

The following Tables show the various substances found in Coals and their Ashes by analysis:—

Table No. 21.

PRODUCTS FROM DESTRUCTIVE DISTILLATION OF COALS.

Name of Coal.	Coke.	Tar.	Water.	Ammonia.	Carbonic Acid.	Sulph. Hydrogen.	Olefiant gas and Hydro-carbon.	Other inflammable gases.
Craigola . .	85·5	1·2	3·1	0·17	2·79	traces	0·23	7·01
Anthracite (Jones & Co.) . . .	92·9	none	2·87	0·20	0·06	0·04	..	3·93
Old Castle Fiery Vein	79·8	5·86	3·39	0·35	0·44	0·12	0·27	9·77
Ward's Fiery Vein .	..	1·80	3·01	0·24	1·80	0·21	0·21	..
Binea . . .	88·10	2·08	3·58	0·08	1·68	0·09	0·31	4·08
Llangennech . .	83·69	1·22	4·07	0·08	3·21	0·02	0·43	7·28

Table No. 22.

INCOMBUSTIBLE MATTERS IN COAL ASHES.

Name of Coal.	Silica.	Alumina and Oxide of Iron.	Lime.	Magnesia.	Sulphuric Acid.	Phosphoric Acid.	Total percentage.
Pontypool . .	40·00	44·78	12·00	trace	2·22	0·75	99·75
Bedwas . .	26·87	56 95	5·10	1·19	7·23	0·74	98·08
Warlich's pat. fuel	25·20	57·30	6·90	trace	7·85	..	99·41
Porthmawr . .	34·21	52·00	6 199	0·659	4·12	0·633	97·821
Ebbw Vale . .	53·00	35·01	3·94	2·20	4·89	0·88	99·92
Fordel Splint .	37·60	52·00	3·73	1·10	4·14	0·88	99·45
Wallsend Elgin .	61·66	24·42	2·62	1·73	8·38	1·18	99·99
Coleshill . .	59·27	29·09	6·02	1·35	3·81	0·40	99·97

Calorific Value.

This was determined chemically and also practically, by enclosing 5 grains of finely powdered coal, with 2000 grains of litharge in an air-tight crucible, and weighing the "button" of lead melted down. The tables give the mean of three separate trials with each fuel. Estimating the heating value of carbon as 13,628, the tabular value multiplied by ·45, gives the lbs. of water which 1 lb. of each fuel should raise from 30° to 212° where the structure of the coals is favourable. As this is not always so, we have preferred the litharge value for practical reference, since the chemical value is from 10 to 12 per cent. higher on the average than the litharge value.

TABLE No. 23.—COMPARATIVE COST, MECHANICAL, COMBUS OF THIRTY-SEVEN VARIE

NAME OF COAL.	COST, per ton, at the Pit.	COST, per ton, at the Nearest Sea port.	MECHANICAL STRUCTURE. Bulk per ton, cubic feet.	MECHANICAL STRUCTURE. Weight per cubic foot—lbs.	MECHANICAL STRUCTURE. Weight of Water in Coals, per cent.	MECHANICAL STRUCTURE. Cohesion of large Coals, per cent.	COMBUSTIBLE Light.	COMBUSTIBLE Draught required.	COMBUSTIBLE Burns.
›eraman, Merthyr . .	2nd sample	10s.	45·80	48·9	·41	74·	ordinary .	quick .	freely .
,, ,, . .	1st sample		43·57	51·4			ord. .	quick .	freely .
›bw Vale . . .			42·26	53·3	1·34	45·	easily .	ord. .	clear .
›omas's Merthyr . .			42·26	53·	1·42	57·5	ord. .	ord. .	freely .
uffryn			42·09	53·22	1·13	56·2	readily .	ord. .	freely and clear
›xon's Merthyr . .		10s.	43·32	51·7	1·22	64·5	difficultly	quick .	stg. flame
nca	7s. to 10s.		39·24	57·08	3·58	51·2	slowly .	ord. .	freely .
›dwas			41·32	50·5	1·28	54·	easily .	ord. .	freely .
›ll's Plymouth Works .		8s. to 9s.	43·74	51·2	1·26	64·	slowly .	quick .	steadily .
›erdare Co.'s, Merthyr .			45·43	49·3	1·40	74·5	ord. .	ord. .	freely .
›dly 9-ft. seam . .			40·87	54·8	1·44	76·	ord. .	strong .	stg. flame
›solven . . .		10s.	38·19	58·66	1·55	35·	easily .	ord. .	strng. open flame
›ynydd Newydd . .			39·76	56·33	·61	53·7	easily .	ord. .	cake and obs.
›ercairn . . .			44·53	50·3	7·11	54·5	easily .	ord. .	cake and obs.
›thracite, Jones & Co. .			38·45	58·25	2·87	68·5	diff. .	quick .	inten. ht.
›ard's Fiery Vein . .	6s. 3d. to 9s.		39·00	57·433	3·01	46·5	easily .	ord. .	freely and
›ath Abbey . . .			37·77	59·3	1·02	50·	easily .	ord. .	freely .
›aigola . . .			37·23	60·166	3·1	49·3	easily .	ord. .	freely .
›dly 4-ft. seam . .			43·41	51·6	1·24	68·5	ord. .	strong .	stg. flame
›achen Rock Vein . .			46·56	48·1	2·5	52·5	easily .	ord. .	clear .
›rch Grove Craigola .			43·92	51·	1·51	59·	ord. .	ord. .	clear and
›ynvi			42·02	53·3	1·13		ord. .	ord. .	steadily .
›doxtan . . .		6s. 6d. to 10s.	38·55	58·1	1·52		diff. .		badly .
›d Castle Fiery Vein .	6s. 6d. to 9s.		43·99	50·916	3·	57·7	easily .	ord. .	freely and expl.
›vian and Son's Mirfa .		7s. 6d.	46·76	47·9	·63	54·0	easily .	moderate	cake and obs.
›angennech . . .			39·34	56·93	4 07	53·5	ord. .	ord. .	slowly .
›ree-quarter Rock Vein .			39·72	56·388	1·67	52·7	easily .	strong .	cake mod.
›ntrepoth . . .			38·80	57·72		46·5	diff. .	ord. .	
›m Frood Rock Vein .		9s. 6d.	40·52	55·277	1·12	72·5	ord. .	ord. .	smoky .
›m Nanty Gros . .			40·	56·	·9	55·7	easily .	ord. .	moderate
›ymbo Main . . .		6s. 8d.	47·65	47·	4·50		quickly .	ord. .	clear .
›vian & Son's Rock Vein .		7s. 6d.	45·80	48·9	1·45	70·5	quickly .	mod. qk.	cake and obs.
›leshill . . .		8s. 6d.	42·26	53·	4·91	62·	quickly .	ord. .	freely .
›ymbo Two-yard . .		7s.	46·76	47·9	3·35	79·5	easily .	ord. .	clear .
›ck Vawr . . .		8s. 6d.	40·72	55·	2·33	65·5	easily .	ord. .	moderate
›rth-Mawr Rock Vein .		9s. to 9s. 6d.	42·02	53·3	1·7	62·	easily .	ord. .	freely .
›ntypool . . .		9s. 6d.	40·21	55·7	1·6	57·5	easily .	ord. .	freely .
›ntrefelin . . .	8s. 9d.		38·85	66·166	1·33	52·7	diff. .	ord. .	bad his. sco.

IBLE, EVAPORATIVE, COKING, AND CHEMICAL PROPERTIES IES OF WELSH COALS.

CHARACTERISTICS.					EVAPORATIVE VALUE.					CHEMICAL COMPOSITION.						
					Steam raised		Water evaporated from 212° by 1 lb. of Coals.									
Attention required.	Smoke.	Clinkers, per ton, Clinkers, lbs.	Residue of Clinkers, Ashes, Cinders, and Soot—per cent.	Calorific Value of 5 grains in Melting Lead—grains.	In Time—mean.	From temp. of Fah.	Power of—lbs.	Realized—lbs.	Rate of, per hour—lbs.	Carbon—per cent.	Hydrogen—per cent.	Oxygen—per cent.	Nitrogen—per cent.	Sulphur—per cent.	Ashes—per cent.	Coke—per cent.
rdinary .	little .	13·3	6·5	159·9	22	198		10·75		90·94	4·28	·94	1·21	1·18	1·45	85·
rd. .	little .	13·0	7·38	159·9	23	209	10·04	9·53								
areful .	moderate	9·5	5·87	159·9	43	187	10·64	10·21	460·22	89·78	5·15	·39	2·16	1·02	1·50	77·5
ittle .	little .	3·9	9·03	164·8	20	209	10·72	10·16	520·8	90·12	4·33	2·02	1·00	·85	1·68	86·5
ittle .	none .	none	7·8	150·0			11·80	10·14	409·33	88 26	4·66	·60	1·45	1·77	3·26	84·3
ittle .	little .	5·7	11·31	166·	38	209	10·7	9·96	511·4	90·27	4·12	2·53	·63	1·20	1·25	79·1
ittle .		none	8·22	158·2	29	216	10·3	9·94	486·95	88·66	4·63	1·03	1·43	·33	3·96	88·1
ittle .	little .	22·9	4·79	141·	26	197	9·99	9·79	476·96	80·61	6·01	1·5	1 41	3·5	6·94	71·7
areful .	little .	7·5	7·01	170·3	42	195	10·18	9·75	531·6	88·49	4·0	3·82	·46	·84	2·39	82·2
ittle .	little .	9·8	8·38	170·6	58	193	10·27	9·73	189·5	88·28	4·24	1·65	1·66	·91	3·26	85·8
areful .	none .	6·0	17·05	170·8	27	208	10·46	9·56	517·3	86·18	4·31	2·21	1·09	·87	5·34	86·5
areful .	little .	none	4·71	160·8	30	198	10·41	9·53	390·25	79·33	4·75	in ash.	1·38	5 07	9·41	83·9
much .	much .	57·2	8·28	151·7	30	208	10·59	9·52	470·69	84·71	5·76	3·52	1·56	1·21	3·24	74·8
much .	mod. .	20· adhes.	4·83	153·8	12	207	9·63	9·47	480·	81·26	6·31	9·76	·77	1·86	2·04	6·8
careful .	none .	little	9·58	167·4	110	194	9·7	9·46	409·37	91·41	3·46	2·58	·21	·79	1·52	92·9
ord. .	little .	54·6	7·44	157·3	48	178	10·6	9·40	529·9	87·87	3·93	in ash.	2·02	·83	7·04	..
frequent .	much .	19·2 adhes.	5·44	156 0	52	155	9·65	9·38	546·1	89·04	5·05		1·07	1·60	3·55	61·4
ord. .	little .	30·7	9·27	160·4	25	209	9·66	9·35	411·48	81·87	3·84	7·19	·41	·45	3·24	85·5
careful .	none .	11·6	20·54	171·2	35	202	10·73	9·29	400·	88·56	4·79		·88	1·21	4·88	88·2
ord. .	little .	12·4	5·26	153·3	22	205	9·13	9·23	488·75	71·08	4·88	17·87	·95	1·37	3·85	65·2
ord. .	little .	28·6 adhes.	9·89	166·3	17	209	9·64	9·22	507·5	84·25	4·15	5·58	·73	·86	4·43	85·1
ord. .	little .	36·	9·07	161·2	30	202	9·58	9·19	399·5	87·18	5·06	2·53	·86	1·33	3·04	72·9
much .	none .	34·70 adhes.	17·63	158·	105	190	9·07	8·97	344·16	87·71	4·34	1·58	1·05	1·75	3·57	82·0
ord. .	little .	none	6·57	157·1	87	162		8·94	464·3	87·68	4·89	3·39	1·31	·09	2·64	79·8
constant .	much .	18· adhes.	5·29	155·7	22	199	9·11	8·92	421·25	82·75	5·31	1·64	1·04	·95	5·31	67·1
ord. .		66·4	11·04	163·3	25	203	9·2	8·86	373·22	85·46	4·20	2·44	1·07	·29	6 54	83·(
ord. .	much .	54·3	7·36	133·1	23	218		8·81	486·86	75·15	4·93	5·04	1·07	2·85	10·96	62·5
careful .	little .	80·	10·47	155·8	62	198	8·98	8·72	381·5	88·72	4·50	3·24	·18		3·36	82·5
ord. .	much .	38·5	7·8	141·5	28	215	9·38	8·70	379·80	82·25	5·84	3·58	1·11	1·22	6·	68·8
careful .	little .	23·3	5·44	148·4	27	205	8·82	8·42	404·16	78·36	5·59	5·58	1 86	3·01	5·6	65·6
little .	much .	10·7	5·12	151·8	17	198	8·56	8·36	435·83	77·87	5·09	9·52	·57	2·73	4·22	55·4
much .	considbl.	30·1 adhes.	4·75	150·	10	203	8·19	8·08	492·5	79·09	5·20	8·34	·66	2·41	4·30	58·(
ord. .	considbl.	39·5	7·78	130·7	22	205	8·34	8·	406·41	73·84	5·14	8·29	1·47	2·34	8·92	56·(
little .	much .	19·5	5·6	147·5	17	189	7·91	7·85	441·66	78·13	5·53	8·02	·54	1·88	5·90	56·2
ord. .	little .	38· adhes.	5·92	144·6	23	198	7·88	7·68	397·5	77·98	4·39	8·55	·57	·96	7·55	62·5
ord. .	much .	25·9	9·54	150·5	32	193	7·75	7·53	347·44	74·70	4·79	3·60	1·28	·91	14·72	63·1
constant .	much .	15·	12·63	137·3	17	207	8·04	7·47	250·4	80·70	5·66	4·38	1·35	2·39	5·52	64·8
ord. .	mod. .	28·6	27·7	152·6	127	162	7·4	6·36	247·24	85·52	3·72	4·55		·12	6·09	85·(

TABLE No. 24.—COMPARATIVE COST, MECHANICAL, COMBUS OF NINETEEN VARIETIES OF THE NEWCASTLE

NAME OF COAL.	COST, per ton, at the Pit.	Nearest Sea port.†	MECHANICAL STRUCTURE. Bulk per ton. cubic feet.	Weight per cubic foot—lbs.	Weight of Water in Coals. per cent.	Cohesion of large Coals. per cent.	COMBUSTIBLE Light.	Draught required.	Burns.
Willington . . .		6s.	42·1	53·2	1·11	43·	difficultly	ordinary .	cakes and obs.
Andrews' House, Tanfield * .		5s. 6d.	42·99	52·1	6·58		easily .		cakes and obs.
,, ,, Coke .	•		74·66	30·				strong .	
Bowden Close . .		6s.	44·26	50·6	1·33	38·5	ordinary .	ord. .	cakes and obs.
Haswell Wallsend . .		9s. 3d.	47·25	47·4	4·08	73·	ord. .	ord. .	cakes and obs.
Newcastle Hartley . .	7s.		44·35	50·5	1·38	78·5	diff. .	strong .	
Hedley's Hartley . .			43·07	52·	1·46	85·5	easily .	quick .	slowly .
Bates West Hartley . .		8s.	44·13	50·8	9·28	69·5	ord. .	mod. qk.	mod. free
West Hartley Main . .		7s. to 7s.6d.	45·80	48·9	6·76	79·	easily .	ord. .	rapidly .
Buddle's West Hartley .		8s.	44·09	50·6	7·24	80·	ord. .	mod. qk.	freely .
Hasting's Hartley . .		7s. 6d.	46·18	48·5	7·88	75·5	easily .	ord. .	freely .
Carr's Hartley . .		7s. 6d.	46·86	47·8	5·60	77·5	easily .	ord. .	mod. .
Davison's West Hartley .		7s. 6d.	46·96	47·7	6·19	76·5	easily .	ord. .	freely .
North Percy Hartley . .		8s.	45·62	49·1	8·41	60·	easily .	ord. .	freely .
Haswell Coal Company's Steamboat Wallsend		8s.	45·25	49·5	1·14	79·5	easily .	ord. .	freely for a time
Derwentwater Hartley .		6s. 6d.	46·44	50·4	12·52	63·5	easily .	ord. .	rapid .
Broom Hill . . .	3s. 4d.		42·67	52·5	9·31	65·7	easily .	mod. qk.	dull flame
Original Hartley . .		7s. 6d.	45·62	49·1	8·11	80·	easily .	ord. .	rapidly .
Cowpen and Sidney's Hartley		7s.	46·76	47·9	10·17	71·	easily .	ord. .	freely .

* 1 lb. of Coals with ordinary draught evaporated 9·39 lbs. at the rate of 351·2 lbs. per hour.
1 lb. ,, uneven draught ,, 9·91 lbs. ,, 526·3 lbs. ,,
1 lb. of Coke ,, ,, ,, 7·91 lbs. ,, 449·3 lbs. ,,
Newcastle Coals are said to have been first mined or "dug," during the reign of Henry III. in 1280.

BLE, EVAPORATIVE, COKING, AND CHEMICAL CHARACTERS

ISTRICT COALS AND ONE SAMPLE OF COKE.

IARACTERISTICS.					EVAPORATIVE VALUE.					CHEMICAL COMPOSITION.						
					Steam raised		Water evaporated from 212° by 1 lb. of Coals.									
Attention required.	Smoke.	Clinkers, per ton, Adhesive. lbs.	Residue of Clinkers, Ashes, Cinders, and Soot—per cent.	Calorific Value of 5 grains in Melting Lead—grains.	In Time—mean.	From temp. of Fah.	Power of—lbs.	Realized—lbs.	Rate of, per hour—lbs.	Carbon—per cent.	Hydrogen—per cent.	Oxygen—per cent.*	Nitrogen—per cent.	Sulphur—per cent.	Ashes—per cent.	Coke—per cent.
onstant .	much .	7· non ad.	5·61	156·5	20	206	10·16	9·95		86·81	4·96	5·22	1·05	·88	1·08	72·19
areful .	much .	3·2	4·5	155·9	40	195	9 8*	9·39	351·2							
								9·91	526·3	85·58	5·31	4·39	1·26	1·32	2·14	65·13
		25·6	5·4		45	203		7·91	149·2							
onstant .	much .	6·6	5·53	158·5	28	203	9·67	9·38		84·92	4·53	6·66	·96	·65	2·28	69·69
uch .	do. & soot	3·5	4·77	157·5	28	199	9·07	8·87	411·66	83.47	6·68	8·17	1·42	·06	·20	62·7
areful .	much .	17·0 non ad.	8·07	159·3	30	202	8·65	8·23	308·.	81·81	5·5	2·58	1·28	1·69	7·14	64·61
onstant .		11·4	11·89	151·8	33	180	8·71	8·16	300·8	80 26	5 28	2·40	1·16	1·78	9·12	72·31
ttle .	much .	1·4	4·48	144·6	27	202	8·26	8·04	406·8	80·61	5·26	6·51	.1·52	1·85	4·25	
rd. .	much .	2·8	4·10	151·8	17	208	8·05	7·87	457·5	81·85	5·29	7·53	1·64	1·13	2·51	59·20
ttle .	much .	5·9	4.82	147·7	35	202	8·01	7·82	413·3	80·75	5·04	7·86	1·46	1·04	3·85	
areful .	little .	1·7	4·59	112·8	20	201	7·96	7·77	404·5	82 24	5·12	6·41	1·61	1·35	2·94	35·6
onsider.	much .	5·0 non ad.	5 76	154·5	28	200	8·13	7·71	314·3	79·83	5·11	7·86	1 17	·82	5·21	60·63
ttle .	consid. .	2·1	4·17	150·6	23	207	7·83	7·61	402·9	83·26	5·31	2·50	1·72	1·38	5·84	59·42
areful .	consid. .	7·8 non ad.	4·86	145·5	28	203	7·72	7·57	423·5	80·03	5·08	9·91	·98	·78	3·22	57·18
onstant .	much .	9·8	10·45	144·	38	184	7·85	7·18	291·8	83·71	5·30	2·79	1·06	1·21	5 93	61·38
ittle .	much .	28·3	6·38	145·5	40	202	7·66	7·42	451·1	78·01	4·74	10·31	1·84	1·37	3·73	54·83
nuch .	little .	5·	3·23	126·6	44	208	7·66	7·3	397·78	81·7	6·17	4·37	1·84	2·85	3·07	59·2
ittle .	much .	10·1	4·27	133·1	66	155	6·98	6·82	428·4	81·18	5·56	8·03	·72	1·44	3·07	58·22
ord. .	much .	3·7	5·69	143·3	27		7·02	6·79	350·4	82·2	5.10	7·97	1·69	·71	2·33	58·59

' † The duty paid on coals and coke last year was £251,547 11s. 7d., of this £175,91 15s. 6d. was for the port of London, and principally on "sea-borne" or Newcastle coal. The railway dues for the rest of the United Kingdom was only £8363 9s. 3d.

TABLE No. 25.—COMPARATIVE COST, MECHANICAL, COMBUS

TWENTY-EIGHT VARIE

LANCA

NAME OF COAL.	COST, per ton, at the		MECHANICAL STRUCTURE.				COMBUSTIBLE		
	Pit.	Nearest Sea port.	Bulk per ton, cubic feet.	Weight per cubic feet—lbs.	Weight of Water in Coals, per cent.	Cohesion of large Coals, per cent.	Light.	Draught required.	Burns.
Ince Hall Companies, Arley .	7s.	9s. 6d.	47·05	47·6	1·07	73·5	easily	ord. .	cake sligh.
Haydock, Little Delf . .			49·88	44·9	3·19	66·5	easily .	ord. .	freely .
Balcarres, Arley . .	6s.		44·35	50·5	1·86	76·	easily .	ord. .	freely .
Blackley, Hurst . .			46·16	48·0	3·66	69·	ord .	ord. .	freely .
Ince Hall, Pemberton Yard .	6s. 6d	8s 6d to 9s 6d	46·66	48·0	2·55	75·5	easily .	ord. .	clear .
Haydock, Rushy Park .			45·43	49·3	1·89	77·	easily .	ord. .	freely for a time
Moss Hall, Pemberton, 4-ft.	6s.		47·35	47·3	3·32	71·5	easily .	ord. .	clear .
Haydock, Higher Florida .			45·25	49·5	6·12	74·	easily .	ord. .	freely for a time
Ince Hall, Pemberton, 4-ft. .	6 .	8s 6d to 9s 3d	43·24	51·8	4·86	74·5	readily .	ord. .	clear .
Blackbrook, Little Delf .	6s to 7s.		43·92	51·	5·58	61·5	easily .	ord. .	freely .
King	8s 6d.	15s.	44·09	50·8	2·84	78·5	easily .	mod. qk.	rapidly .
Rushy Park Mine . .	7s		47·65	47·	11·66	67	easily .	ord. .	clear .
Blackbrook, Rushy Park .	6s. to 7s.		40·5	55·3	5·90	80·5	easily .	ord. .	freely .
Johnsons & Worthingtons, Rushy Park . . .			44·8	50·	7·15	69·	easily .	ord. .	clear .
Laffak, Rushy Park . .	7s 6d.		42·58	52·6	6·24	75·5	easily .	ord. .	clear .
Balcarres, Haigh Yard .	6s.	9s.	44·13	50·8	2·69	80·	easily .	ord. .	steadily .
Haydock, Florida Vein .			46·66	48·0	6·61	81·5	easily .	ord. .	freely for a time
Wigan, 4-ft. . . .	5s. 6d. to 6s.	9s. to 9s. 6d.	41·94	53·4	2·69	75·	easily .	ord. .	rapidly .
Ince Hall, Pemberton, 5-ft. .	5s. 6d.	8s.	43·24	51·8	4·75	71·5	easily .	strong .	freely for a time
Cannel (Wigan) . .	10s. to 12s.	14s. to 18s.	46·37	48·3	1·01	95·	easily .	ord. .	freely .
Ince Hall Cos. Furnace Vein	5s. 6d.	7s. 6d. to 8s.	45·43	49·3	5·33	71·5	easily .	ord. .	freely for a time
Balcarres, Lindsay . .	6s. 8d.		43·83	51·1	6·47	70·	easily .	quick .	stead. for a time
Caldwell & Thompsons, Rushy Park . . .	5s. 6d. to 7s.	8s. to 9s. 6d.	47·15	47·5	4·97	76·	easily .	ord. .	clear .
Balcarres, 5-ft. . .	6s. 8d.		45·71	49·	7·12	44·5	easily .	ord. .	freely
Moss Hall, Pemberton, 5-ft.	5s.		46·37	48·3	3·69	78·5	easily .	ord. .	freely for a time
Moss Hall Cos. New Mine .	5s.		46.28	48·4	6·76	76·5	easily .	ord. .	freely for a time
Caldwell & Thompsons, Higher Delf . . .	5s. 6d. to 7s.	8s. to 9s. 6d.	46·28	48·4	0·98	77·	easily .	consid. .	clear for a time
Johnsons & Worthingtons Sir John . . .	6s	9s.	48·41	51·6	4·02	82·	diff. .	strong .	slowly .

'IBLE, EVAPORATIVE, COKING, AND CHEMICAL QUALITIES OF
'IES OF LANCASHIRE COALS.

HIRE.

'HARACTERISTICS.					EVAPORATIVE VALUE.					CHEMICAL COMPOSITION.						
					Steam raised		Water evaporated from 212° by 1 lb. of Coals.									
Attention required.	Smoke.	Clinkers, per ton. Adhesive, lbs.	Residue of Clinkers, Ashes, Cinders, and Soot—per cent.	Calorific Value of 5 grains in Melting Lead—grains.	In Time—mean.	From temp. of Fah.	Power of—lbs.	Realized—lbs.	Rate of, per hour—lbs.	Carbon—per cent.	Hydrogen—per cent.	Oxygen—per cent.	Nitrogen—per cent.	Sulphur—per cent.	Ashes—per cent.	Coke—per cent.
ord.	much	·107 adhes.		162·5	22	204	9·55	9·47	487·29	82·61	5·86	7·44	1·76	·8	1·53	64·
much	much	9·6		146·6	13	197	9·26	9·13	532·91	79·71	5·16	10·65	·54	·52	3·42	58·1
ord.	much	11·0 adhes.	5·68	147·0	18	205	9·09	8·83	451·1	83·54	5·24	5·87	·98	1·05	3·32	62·89
ord.	much	10·8	3·74	147·9	28	192	9·00	8·81	500·8	82·01	5·55	5·28	1·68	1·43	4·05	57·84
ord.	much	12·2 non ad.	4·9	150·2	13	205		8·78	461·25	80·78	6·23	7·53	1·30	1·82	2·34	60·6
much	much	7·8 adhes.	3·39	149·	12	209	8·91	8·74	461·66	77·67	5·53	10·91	·50	1·73	3·68	59·4
ord.	much	7·1 adhes.	3·39	142·5	22	204	8·65	8·52	480·	75·53	4·82	7·98	2·05	3·04	6·58	55·7
much	much	13·2	3·62	148·6	9	210	8·49	8·39	467·5	77·33	5·56	12·02	1·01	1·03	3·05	51·1
little	consid.	2·1	3·52	144·3	28	193	8·45	8·34	497·39	77·01	3·93	5·52	1·40	1·05	1·09	57·1
careful	much	none	3·55	143·4	33	185	8 55	8·29	440·1	82·7	5·55	4·89	1·48	1·07	4·31	58·48
careful	much	47·1 adhes.	3·55	136·4	22	203	8·35	8·17	395·41	73·66	5·30	9 06	1·68	1·58	8·72	62·4
ord.	consid.	2·7	3·14	144·9	23	193	8·35	8·08	419·1	77·76	5·23	8·99	1·32	1·01	5·69	56·66
careful	little	2·1 adhes.	2·77	151·8	20	198	8·26	8·02	481·2	81·16	5·99	7·20	1·35	1·62	2·68	58·10
ord.	much	8·6	3·64	144·5	28	199	8·16	8·01	454·5	79·5	5·15	9·21	1·21	2·71	2·19	57·52
	much	5·1	3·78	134·0	22	203	8·16	7·98	435·	80·17	5·72	8·33	1·27	1·39	2·82	56·26
ord.	much	26·4 adhes.	8·34	140·8	23	207	8·23	7·9	398·3	82·26	5·47	5·64	1·25	1·48	3·90	66·09
much	much	9·	3·97	146·3	12	209	8·97	7·83	422·5	77·49	5·50	12·84	1·27	·88	2·02	54·4
ord.	much	37·6	7·98	150·1	20	207	8·05	7·77	414·79	78·86	5·29	9·57	·86	1·19	4·23	60·
much	consid.	20·4 adhes.	8·74	143·7	23	208	7·95	7·72	495·2	68·72	4·76	18·63	2·20	1·35	14·34	56·5
careful	much	21·1 adhes.	7·84	148·7	20	194	8·06	7·70	381·1	79·23	6·08	7·24	1·18	1·43	4·84	60·33
careful	much	25·3 adhes.	7·40	143·	13	211	7·84	7·47	435·21	71·74	5·71	13·52	1·53	·96	4·01	58·4
ord.	much	22·3	4·93	131·	25	203	7·58	7·44	431·5	83·9	5·66	5·53	1·40	1·51	2·00	57·84
little	consid.	5·1	2·38	147·1	22	203	7·43	7·31	449·79	76·17	5·46	14·87	1·09	·91	1·50	58·7
ord.	much	21·8	4·77	129·8	20		7·35	7·21	489·5	74·21	5·03	8·69	·77	2·09	9·21	55·90
much	much	31·9 adhes.	6·35	137·4	20	202	7·29	7·13	417·18	76·16	5·35	10·13	1·29	1·05	6·02	56·1
		34·2 adhes.	5·86	135·1	23	204	7·16	7·04	422·08	77·50	4·84	12·16	·98	1·36	3·16	57·7
much	much	38·6 adhes.	5·85	141·8	40	188	6·94	6·85	484·28	75·40	4·83	19·98	1·41	2·43	5·95	54·2
much		34·4	9·42	119·	22	209	6·62	6·32	362·7	72·86	4·98	8·15	1·07	1·54	11·4	56·15

Table No. 26.—Comparative cost, mechanical, combustible,

varieties of Derbyshire, eight of Scotch coals, six

DERBY

NAME OF COAL.	COST, per ton, at the Pit.	Nearest Sea port.	MECHANICAL STRUCTURE. Bulk per ton. cubic feet.	Weight per cubic feet—lbs.	Weight of Water in Coals, per cent.	Cohesion of large Coals, per cent.	COMBUSTIBLE Light.	Draught required.	Burns.
Earl Fitzwilliam's Elsecar		5s. 9d.	47·45	47·2	4·83	77·	easily	mod.	freely
Hoyland & Cos. Elsecar		5s. 9d.	46 47	48·2	3 72	82·5	easily	mod. qk.	freely
Earl Fitzwilliam's Park Gate			47·65	47·	3 08	78·	easily	mod. qk.	freely
Butterly Cos. Portland		6s. 9d.	47·55	47·1	7·36	89·	easily	mod. qk.	free
Butterly Cos. Longley		6s.	46·86	47·8	3·55	84·5	easily		free
Staveley		9s.	44·88	49·9	8·54	88·5	easily	ord.	freely
Loscoe, Soft	5s. to 7s.		50·0	44·8	9·76	62·	readily	ord.	freely for a time
Loscoe, Hard	5s. to 7s.		48·8	15·9		86·	readily	ord.	freely for a time
									SCOT
Elgin Wallsend			41·02	54·6	2·49	64·	easily	ord.	freely
Wellewood		8s. 6d.	42·58	52·6	2·77	80·	easily	ord.	freely
Dalkeith Coronation			43 36	51·66	5·3	88·2	easily	ord.	freely
Kilmarnock Shevington		6s.	50·11	44·7	7·76	63·5	easily	ord.	freely
Fordel Splint		9s.	40 72	55·0	8·4	63·	easily	ord.	stg. flame
Grangemouth		9s.	40 13	51·25	6·42	69·7	easily	ord.	mod.
Eglinton		7s. 4d.	43·07	32·0	10·02	79·5	easily	ord.	rapid
Dalkieth Jewel			44·98	49·8	9·7	85·7	easily	ord.	freely
									VARI
Slievardagh Irish Anthracite	20s. to 25.		35·66	62·8	4·93	74·	difficultly	strong	clear
Coleshill Co.'s Bagilt Main		7s.	45·16	49·6	5·50	79.	easily	ord.	freely
Ewloe			44·44	50·4	6·83	84·	easily	quick	clear
Ibstock	7s. 6d.		47·35	17.3	1·12	62·	easily	quick	clear
Forest of Dean (Lydney)		10s. to 11s.	41·14	54·44	2·78	55·	easily	mod.	smoky
Conception Bay (Chili)					13·52		easily	ord.	freely
									PATENT
Warlich's Patent Fuel			32·44	9·05	·92		slowly	ord.	mod.
Livingstone's Steam Fuel			34·14	65·6	1·39		difficultly	ord.	slowly
Lyon's Patent Fuel			36·66	61·1	1·91				mod.
Wylam's Patent Fuel			34·41	65·08	1·38		readily	quick	freely
Bell's Patent Fuel			34·30	63·3	·9		slowly	ord.	ord.
Holland and Green's			34·56	64·8	2·18		easily		freely for a time

APORATIVE, COKING, AND CHEMICAL PROPERTIES OF EIGHT
HER VARIETIES, AND SIX VARIETIES OF PATENT FUEL.

IRE.

ARACTERISTICS.					EVAPORATIVE VALUE.					CHEMICAL COMPOSITION.						
					Steam raised		Water evaporated from 212° by 1 lb. of Coals.									
Attention required.	Smoke.	Clinkers, per ton, Adhesive, lbs.	Residue of Clinkers, Ashes, Cinders, and Soot—per cent.	Calorific Value of 5 grains in Melting Lead—grains.	In Time—mean.	From temp. of Fah.	Power of—lbs.	Realized—lbs.	Rate of, per hour—lbs.	Carbon—per cent.	Hydrogen—per cent.	Oxygen—per cent.	Nitrogen—per cent.	Sulphur—per cent.	Ashes—per cent.	Coke—per cent.
ch .		6·6	5·95	150·5	23	198	8·78	8·52	412·7	81·93	1·85	8·58	1·27	·91	2·46	61·6
ch .	much .	1·7	7·9	148·6	23	197	8 43	8·07	372·91	80·05	4·93	8 99	1·24	1·06	3·73	62·5
ch .		none	7·60	150·6	22	199	8·24	7·92	393·75	80 07	4·92	9·95	2·15	1·11	1·80	61·7
eful .	much .	10·3 non ad.	4·39	155·2	22	199	8·01	7·92	487·08	80·41	4·65	11·26	1·59	·86	1·23	60·9
eful .	much .	10·0	6·48	150·	15	209	7·98	7·8	398·69	77·97	5·58	9·86	·80	1·14	4·65	54·9
. .	much .	12·6	4·78	140·4	22	207	7·40	7·26	466·2	79·85	4·84	10·96	1·23	·72	2·40	57·8
at	much .	8·4 adhes.	3·36	140·2	22	208	7·99	6·88	490·06	77·49	4 861	2·41	1·64	1·30	2·03	52·8
at .	much .	8·5 adhes.	4·64	147·9	18	208		6·32	431·42							
I.																
le	. consid. .	14·5	4·73	145·3	28	203	8·67	8·46	435·77	76·09	5·22	5·05	1·41	1·53	10·70	58·45
le	. much .	28·5	4·50	142·4	35	181	8·39	8 24	438·5	81·36	6·28	6·37	1·53	1·57	2·89	59·15
le	. little .	62·2	5·9	122·8	30	180	7·86	7·71	370·08	76·94	5·2	14·37	trace	·38	8·10	53·5
eful	. much .	6·4	3·42	151·6	17	202	7·82	7·66	470·83	79·82	5·82	11·31	·91	·86	1·25	49·3
le	. consid. .	3·	2·86	145·0	40	176	7·69	7·56	464·98	79·58	5·5	8·33	1·13	1·46	4·0	52·03
l.	. little .	16·4	5·26	142·4	28	208	7·91	7·40	380·4	79·85	5 28	8·58	1·35	1·42	3·52	56·6
l.	. much .	82· non ad.	4·03	121·6	33	186	7·48	7·37	406·2	80·08	6 5	8·05	1·55	1·38	2·44	54·94
le	. little .	59·5	3·92	132·1	40	193	7·1	7·08	355·18	74·55	5·14	15·51	·10	·33	4·37	49·8
US.																
eful .	none .	17·9	7·25	150·5	110	150	10·49	9·85	173·18	80·03	2·3	in ash.	·23	·76	10·8	90·1
l. .	mod. .	5·7	3·92	152·	28	197	8·5	8·33	461·25	88·48	5·62	·86	2·02	1·36	1·62	55·8
eful ,	mod. .	4·4	4·72	135·6	17	208	7·16	7·02	363·95	80·97	4·96	8·20	1·1	1·4	3·37	54·5
eful .	little .	14·1 non ad.	4·10	125·5	20	206	7·02	6·91	454 16	74·79	4·83	11·88	·88	1·45	5·99	50·8
l. .	much .	2·45	4·06	129·7	20	218	8·98	8·52	487·19							
eful .	much .	44·5 ad.	8·48	128·1	30	208	5·96	5·72	425·							
JELS.																
reful .	little .	29·6	6·79	157·5	30	203	10·60	10·36	457·84	90·02	5·56	in ash.	trace	1·62	2·91	85·1
uch .	little .	28·2	10·95	162·7	33	194	10·57	10·03	483·95	86·07	4·13	2·03	1·80	1·45	4·45	
uch .	much .	38·7	6·06	156·9	38	189	9·77	9·58	409·1	86·36	4·56	2.07	1·06	1·29	4·66	
d. .	mod. .	59·5	7·27	144·1	35	199	9·74	8·92	418·89	79·91	5·69	6·63	1·68	1·25	4·84	65·8
eat .	consid. .	76·1	6·7	142·6	37	201	8·65	8·53	549·11	87·88	5·22	0·42	·81	·71	4·96	71·7
uch .	consid. .	87·6	12·55	118·4	22	204	7·86	7·59	470·0	70·14	4·65		1·15		13·73	

TABLE No. 27.

SUMMARY OF THE MEAN AVERAGES OF THE COALS FROM DIFFERENT LOCALITIES.

	MECHANICAL STRUCTURE.			EVAPORATION OF WATER.			CHEMICAL COMPOSITION						
	Bulk of 1 ton cub ft.	Weight of 1 cub foot, lbs.	Cohesion per cwt of large coals	By 1 lb of coals lbs.	Per hour. lbs	Sulphur per cent.	Carbon per cent	Hydrogen per cent	Oxygen per cent.	Nitrogen per cent	Sulphur per cent.	Ashes per cent.	Coke per cent
Welsh, 37 Samples .	42·71	53·1	60·9	9·05	448·2	1·42	*83·78	4·79	4 15	0 98	1·43	4·91	72·6
Newcastle, 17 ditto .	45·3	49·8	67·5	8·37	411·1	0·94	82·12	5·31	5·69	1·35	1·24	3·77	60·67
Lancashire, 28 ditto .	45·15	49·7	73·5	7·94	447·6	1·42	77·0	5·32	9·53	1 930	1·44	4·83	60·22
Scotland, 8 ditto .	49·99	50·	73·4	7·7	431·4	1·45	78·53	5·61	9·69	1·0	1·11	4·03	54·22
Derbyshire, 8 ditto .	47·45	47·2	80·9	7·58	432·7	1·01	†79·68	4·94	10·28	1·41	1·01	2·65	59 22

* Mean of 36 samples. † Of seven experiments.

Table No. 28.

CHEMICAL COMPOSITION OF VARIOUS FOREIGN AND COLONIAL COALS.

VAN DIEMEN'S LAND.

Name.	Water.	Carbon.	Hydrogen.	Oxygen.	Nitrogen.	Sulphur.	Ash.
South Cape .	3·33	63·1	2·89	1·01	1·27	·98	30·45
Mnt. Nicholas Break o'Day	7·24	57·37	3·91	9·10	1·15	·90	27·55
Tingal . .	1·86	57·21	3·38	7·8	1·2	1·32	29·09
Jerusalem . .	3·06	68·18	3·99	5·89	1·62	1·12	19·20
Douglas River East Coast .	4·87	70·44	4·20	9·27	1·11	·70	14·38
Tasman's Peninsula	4·40	65·54	3·36	1·75	1·91	1·03	26·41
Schoten Island .	2·17	64·01	3·55	3·38	·94	·85	27·17
Whale's Head South Cape	1·72	65·86	3·18	7·20	1·12	1·14	21·50
Adventure Bay .	3·81	80·22	3·05	4·8	1·36	1·9	8·67
VARIOUS.							
Sydney, New South Wales	3·25	82·39	5·32	8·32	1·23	·70	2·04
Borneo Labuan .		64·52	4·74	20·75	·80	1·45	7·74
,, 3ft. Seam		54·31	5·03	24·22	·98	1·14	14·32
,, 11ft. Seam		70·33	5·41	19·19	·67	1·17	3·23
Formosa Island .		78·26	5·7	10·95	1·64	·49	3·96
Vancouver's Island .	7·21	66·93	5·32	8·7	1·02	2·2	15·83
Lignite, Trinidad	2·62	65·20	4·25	21·69	·33	·69	6·84
CHILIAN.							
Conception Bay .		70·55	5·76	13·24	0·95	1·98	7·52
Port Famine .	14·63	64·18	5·33	22·75	0·50	1·03	6·21
Chirique .	9·11	38·98	4·01	13·38	·58	6·14	36·91
Laredo Bay . .	16·03	58·67	5·52	17·33	·71	1·14	16·63
Talcahnano Bay.	12·43	70·71	6·44	13·95	1·08	·94	6·92
Colcurra Bay .	5·89	78·30	5·50	8·37	1·09	1·06	5·68
PATAGONIAN.							
Sandy Bay No. 1	22·68	62·25	5·05	17·54	·63	1·13	13·4
,, No. 2	22 26	59·63	5·68	17·45	·64	·96	15·64
Juan Fernandez .	6·06						

TABLE NO. 29.

CHEMICAL ANALYSIS OF FORTY-TWO VARIETIES OF AMERICAN COALS.

ANTHRACITE.				BITUMINOUS.			
Name.	Carbon, per cent	Gases per cent.	Ashes per cent	Name.	Coke.	Gases.	Ashes
Nesquehoning	86·6	6 4	7·	Hopewell Furnace . . .	88·2	11·2	4·
Le High Summit	88·5	7·5	4·	Lick Run	79·28	20·72	13 07
„ hardest . .	87·7	6·6	5 7	Queen's Run . . .	78·28	21·2	2·07
Tamaqua D Vein	92·07	5 03	2 9	Moshanna Creek . . .	70·50	29·5	6·1
„ E Vein	89·2	4 54	6 26	Steed's Mine . . .	79·6	20·4	11·20
„ R Vein	87·45	7·55	5·10	Leech's Mine . . .	79·68	20 32	11·75
Fuscurora	88·2	7 5	4 3	Ralstan Lyconing Company . .	79·50	20·5	5·
Pottesville Schuyl Comp. Schenewith	94·1	1 4	4·5	Karthaus Upper Seam . .	87·	13·	8·80
Neeley's Tunnel	89·2	5 4	5 4	„ Lower Seam . .	75·2	24·8	4·70
Sharp Mountain P. G.	80 57	7 15	3·28	Reed's Six-Feet Vein Curwinsville .	73·	27·	5·30
Black Spring Gap	82·47	9 53	8 00	Bear Creek	68·	32·	5·20
„ Lea Vein . .	85·84	8 96	5 20	Warner's Caledonia Three Feet .	61·8	38·2	7·20
„ Grey Vein . .	81·02	9 78	9 20	„ „ Five Feet .	63·	37·	8·5
Gold Mine Gap Pea. Vein . .	82 15	10 95	6 90	Blairsville	69·	31·	4·
„ Heister Vein . .	81·47	10 63	8·1	Sandy Ridge	56·8	43·2	7·
Yellow Spring Gap	79 55	10 95	9 50	Venango Company's Cannel . .	47·22	52·78	17·68
Ruttling Vein	74·55	15 75	11 70	Greersberg . . .	64·0	36·0	33·88
Big Flats	76·94	13 06	8 0	Coneant Lake . . .	61·25	38·75	1·8
Lyken's Valley	88·25	8 85	2 90	Greenville	59·5	40·5	1·7
Shamohin	89·90	6 10	4·	Orangeville	56·25	43·75	2·8
Wilkesbare Ward.	88 9	7·68	3 42	Snowshoe	78 8	21·2	2·07
„ „ Carbondale .	90·23	7 07	2 70				

NOTE.—All the varieties contain more or less of sulphur. In the anthracite running from 48 to 91 per cent. of the ashes and in the bituminous from 2·6 to 2 7 per cent. The general characteristics of each kind are for anthracite, ecomomy of space, freedom from smoke and cleanliness; for bituminous, free combustion, smokiness, and less durability than the anthracite.

The ratio of carbon in coals, it is thus seen, varies considerably; so also does the quantity of hydrogen. Generally, bituminous coals yield less carbon than anthracite coals, but more hydrogen. Bitumen renders coals easily ignited and smoky, whilst it gives them that caking quality so much appreciated for domestic use in London, by melting the coals together, thereby closing the top of the fire, and, by preventing the heat being so rapidly carried up the chimney, causes it to radiate more into the apartment. It also at the same time tends to prevent light ashes flying about, an evil so much complained of with less bituminous coals.

The waste of heat which takes place in ordinary fires, by about two-thirds of it passing up the chimney, is well known; yet how few fire-places are constructed otherwise than to increase this waste, or "draught," as it is called. A better class of radiating fire-places, at once elegant and economical, seems still to be a desideratum, where custom and prejudice hold so firm a sway as to prevent attention to either comfort or cost.

Dr. Arnott's experiments showed that full one-half the heat evolved was carried directly up the chimney; a large portion of that radiated outwards was immediately drawn back into the chimney, and only a small proportion of the whole into the apartment. Many of the open burning coals contain more carbon, and give out more heat by about 10 per cent. in steam-boiler furnaces than the Newcastle caking coals.

Anthracite contains more carbon than bituminous coals, is more clean, by burning nearly free from smoke, and is now variously used.

The following is the average range of variation in 100 lbs. of each fuel:

BITUMINOUS COALS.

Carbon	53 to 88	lbs. in every 100 lbs. of coals	
Volatile gases (nitrogen, oxygen, and hydrogen)	44 to 10·5	lbs.	„
Ashes	3 to 1·5		„
Total	100 or 100		

ANTHRACITE.

Carbon	75 to 94	lbs. in every 100 lbs. of coals	
Volatile gases (nitrogen, oxygen, and hydrogen)	14 to 1·5	lbs.	„
Ashes	11 to 4·5		„
Total	100 or 100		

The coal tables supply a detailed analysis of each of the numerous varieties therein named.

Not only to coal-mine proprietors and engineers, but also to other coal consumers, will these tables be useful, either for comparison or selection in the railway-extended and extending field of choice and competition. For instance, London, besides its usual supply of "sea-borne" coals, now commands Newcastle, Yorkshire, and Derbyshire coals, cheaply supplied by the Great Northern Railway; the Lancashire coals by the London and North Western Railway; and will also shortly command, equally cheap, nearly all the tabulated varieties of the superior Welsh coals by the Great Western Railway.

These several sources of supply embrace coals of every variety, and the tables supply the correct general character of each coal-field and of many individual sorts by name, which can scarcely fail to be useful to a wide circle, either directly interested in steam-engine or household consumption of coals.

It may be remarked, that for London alone, in 1848, 3,380,786 tons, and in 1849, 3,479,189 tons of coals, paid the city duty of 13*d.* per ton as brought within the Port-boundaries either by sea or inland conveyance; and that during the year ending last July, 271,066 tons of coals were exported from Liverpool, of which 143,037 tons were to the continent of America.

The coals in the following countries are thus approximately estimated:

	Area, Sq. Miles.	Tons dug in 1845.
In Great Britain:		
Bituminous	8139	31,500,000
Anthracite and culm	3720	
In the United States:		
Bituminous	133,132	1,750,000
Anthracite	437	2,650,000
In France	1719	4,141,600
In Spain	3408	
In Belgium	518	4,960,000
In Prussia		3,500,000
In Austria		700,000

The quantity raised now in Great Britain is estimated as about 36 millions of tons, of which about 2 millions are exported, 8 millions consumed in iron-making, and $\frac{3}{4}$ of a million in making coal gas for general use.

In making coal gas for illumination, the quantity of hydrogen evolved varies from about 5000 to 11,800 cubic feet per ton of coals, and is thus estimated:

Scotch cannel . .	11,800 cubic feet of gas
Lancashire cannel . .	11,600 ,,
Newcastle . .	9,600 ,,
Staffordshire . .	6,400 ,,
Wallsend .	10,300 ,,
Templemain . .	6,200 ,,
Tenby . .	4,200 ,,

Besides lighting purposes, the heating power of gas is now drawing attention to its domestic economy. Mr. Defries raised the temperature of 45 gallons of water from 50° to 100° Fahr. by 30 cubic feet of gas, at a cost of $1\frac{1}{2}d$. Mr. Evans estimates the heating power of 1 cubic foot of Newcastle coal gas as equal to boil off into steam 22 times its own weight of water, and practically boiled off from 12 to 13·6 times its own weight as below:

Gas burnt cubic ft.	WEIGHT OF GAS.		WATER BOILED.		Heating power. Ratio.
	Grs.	Spe. grav.	lbs.	Ratio to gas.	
1	206	·416	—	—	22
1	205	·413	·4	13·6	—
1	290	·564	·5	12·0	—
1	360	·700	·7	13·6	—

Evaporative Value of the Hydrogen in Coals.

It has been usual, as previously stated, to regard the heat given out by the combustion of hydrogen as little more than compensating for its production, and that by the quantity of carbon in any fuel its evaporative value was indicated. The following useful table shows the theoretical duty possible by 1 lb. of coals, by the coke in 1 lb. of coals, and by the hydrogen in 1 lb. of coals, with the total theoretical compared with the realized duty.

TABLE No. 30.

THEORETICAL AND PRACTICAL DUTY OF *1lb.* OF COALS, AND ITS CONSTITUENT PARTS.

NAME OF FUEL.	Water converted or convertible into Steam. Theoretically convertible: By 1 lb. of coal. Total.	From the hydrogen in 1 lb. of coals.	From the carbon in 1 lb. of coals.	Practically converted by 1 lb. of coals.	Theoretically convertible by the coke in 1 lb. of coals.	Force or power of 1 lb. of coals: Equal to a weight raised 1 ft. high. Practical.	Is capable of raising 1 ft. high. Theoretical.
	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.
Graigola . . .	13 563	1 903	11·660	9·35	11·301	7·060·908	10·242·471
Anthracite { Jones, Aubrey, & Co. }	14·593	2·030	12·563	9·46	12·554	7·143·978	11·020 303
Oldcastle Fiery Vien .	14·936	2·890	12·046	8·94	10·601	6·751·285	11·279·329
Ward's Fiery Vien .	14 614	2·542	12·072	9·40	.	7·098 667	11·036·162
Binea	15·093	2 912	12·181	9·94	11·560	7·506·463	11·397·89
Llangenock . .	14 260	2 519	11·741	8·86	10 599	6·690·871	10·768 829
Pentripoth . .	14 838	2·649	12·189	8·72	10·873	6·585·116	11·205·322
Pentrefellin . .	13·787	2·038	11·749	6·36	10·841	4 802·928	10·411·630
Powell's Duffryn .	15 092	2·966	12 126	10·149	11 831	7·664·295	11·397 137
Mynydd Newydd .	14 904	3·441	11·463	9·52	9·831	7·189·288	11·255·163
Three-quarter Rock Vein . . .	13·106	2·781	10·325	8·84	7·081	6·675·768	9·897·355
Cwm Frood Rock Vein	14·788	3·488	11·300	8·70	8 628	6·570·043	11·167·563
Cwm Nanty Gros .	13 932	3·165	10·767	8·42	8 243	6 358·593	10 521·131
Resolven . . .	13·971	3·072	10·899	9·53	10·234	7·196·840	10·550·583
Pontypool . . .	14·295	3·207	11·088	7·47	8·144	5·641·175	10 795·260
Bedwas . . .	14·841	3·766	11·075	9 79	8·879	7·393·186	11·207·587
Ebbw Vale . . .	15·635	3·300	12·335	10·21	10·441	7·710·361	11·025·198
Porthmawr Rock Vein	12 811	2·548	10·263	7·53	6 647	5·686 485	9·674·577
Coleshill . . .	12 799	2·654	10·145	8·0	6·468	6 041·419	9·665·515
Dalkeith Jewel Seam	12·313	2·071	10·242	7·08	6·239	5·346·655	9·298·499
Dalkeith Coronation .	12·772	2·202	10·570	7·71	6·924	5 822·417	9 645·125
Wallsend Elgin . .	13·422	2·968	10·454	8·46	6·560	6·388·800	10 135·991
Fordel Splint . .	13·817	2·884	10·933	7·56	6·560	5·709·141	10 434·286
Grangemouth . .	13·692	2·722	10·970	7·40	7·292	5·588·312	10·339·888
Broomhill . . .	14·863	3·638	11·225	7·30	7·711	5·512·795	11·224·201
Park End, Lydney .	13·257	3·156	10·101	8·52	6·567	6·434·111	10·011·386
Slievardagh (Irish) .	12·482	1·487	10·995	9·85	10·895	7·438·497	9·426·124
Formosa Island . .	13·553	2·801	10·752	...	...	...	10·234 919
Borneo (Labuan kind)	10·252	1·388	8·864	...	...	...	7·742·078
„ 3-feet seam .	8·756	1·295	7·461	...	...	...	6·612·333
„ 11 „ .	11·600	1·948	9·652	. .	...	...	8·760·057
Wylam's Patent Fuel	14·331	3·145	11·186	8·92	8·378	6·736 182	10·822·447
Warlich's . . .	15·964	3·596	12·368	10·36	11·292	7·823·637	12·955 652
Bell's	15·417	3·343	12·074	8·53	9·168	6 441·663	11·642 569

The respective evaporative values are estimated by taking 13268 as the unit of heat in a pound of carbon, and 62470 as the unit of heat in a pound of hydrogen, and dividing by the vaporization heat of 965·7°. The coke value is obtained by subtracting from it the quantity of ashes due to the coals, and considering the remainder as carbon.

By this table it is observed that although there are striking exceptions, the work capable of being done by the coke alone is greater generally than that obtained from the coal.

A closer examination of the experiment at the Par Consols mine appears, however, to indicate that the hydrogen does exercise a beneficial result on the evaporative powers of the fuel. The quantity of water evaporated was 11·428 lbs. by 1 lb. of coals, and their composition was 84·19 of carbon, 4·19 of hydrogen, 86 of oxygen, 8 of nitrogen, 1·9 of sulphur, and 8·06 of ashes. The water being at 212° temperature required only 965·7° of heat to convert it into steam. Taking Dulong's values of 13268° of heat for carbon, and 62470° of heat for hydrogen, in this instance, we can readily compare the theoretical with the practical effect.

Theoretically we have,

$$\text{Carbon} = \frac{84 \cdot 19 \times 13268}{100 \text{ lbs.} \times 965 \cdot 7} = 11\ 567 \text{ lbs. of water,}$$

$$\text{and for hydrogen} = \frac{4 \cdot 19 \times 62470}{100 \text{ lbs.} \times 965 \cdot 7} = \underline{2 \cdot 71} \text{ lbs. of water,}$$

total theoretical value of 1 lb. of coals = 14·267 or

$$\begin{aligned} \text{together, carbon} &= 84 \cdot 19 \times 13268 = 1117032 \cdot 92 \\ \text{hydrogen} &= 4 \cdot 19 \times 62470 = \underline{261749 \cdot 30} \\ & \qquad 1378782 \cdot 22 \end{aligned}$$

as the units of heat in 100 lbs. of coals, which being divided by the evaporative heat of 965·7° × 100 lbs. of coals = 14·277 lbs. of water, capable of being evaporated by 1 lb. of these coals.

Practically, 1 lb. of coals evaporated 11·428 lbs. of water from 212°, or only ·139 lbs. less than the theoretical value of carbon, but this 11·428 lbs. was not all the heat actually obtained from the fuel. For it is stated that by an arrangement of water-pipes in the flues, the feed-water was heated to about 212°, by the heat absorbed from the passing gases on their way to the chimney, where their temperature was still 300°. Taking the ordinary temperature of water as 52°, it requires to absorb 160° to raise it to 212°, hence the actual evaporation of $\frac{10{\cdot}204 \times 160}{965{\cdot}7} = 1{\cdot}690$ lbs. of additional evaporative heat from the coals, making 11·894 lbs. as the total heat absorbed, or ·327 lbs. more than was possible by the carbon, and 2·37 less than the total theoretic value of 1 lb. of coals. Without considering the 300° of heat still left to escape up the chimney, the beneficial effect of the hydrogen in the evaporative results is quite evident.

The Mynydd Newydd coals having a similar large proportion of hydrogen (4·28 per cent.), it will be seen by the table that they have a higher practical value than several others possessing more carbon, but less hydrogen.

Taking as another example the Aberaman Merthyr coal, containing 90·94 per cent. of carbon, and 4·28 of hydrogen, possessing the highest evaporative value in these tables, or 10·75 lbs. under the experimental boiler:

For the Cornish boiler the evaporation would be

$10{\cdot}75 \times 1{\cdot}1995 = 12{\cdot}894$ lbs., and as before,

Carbon $90{\cdot}94 \times 13268 = 1206591{\cdot}92$, or 12·494 lbs.
Hydrogen $4{\cdot}28 \times 62470 = 267371{\cdot}60$, or 2·769 lbs.

$\frac{1473963{\cdot}52}{100 \times 965{\cdot}7} = 15{\cdot}263$ lbs. as the theoretic value of 1 lb. of these coals.

Taking the absorption of carried heat by the feed-water to be, as before, equal to 160° for the quantity evaporated, we have $\frac{10 \cdot 75 \times 160}{965 \cdot 7} = 1 \cdot 781$ lbs. as its value,

and $10 \cdot 75 + 1 \cdot 781 = 12 \cdot 531$ lbs. or ·037 more effect from an inferior boiler than due to the carbon.

If the heating values assigned to carbon and hydrogen be correct, it is very gratifying to find so fair an approximation of practice to theory.

These examples from experiments made by a Government officer for official purposes only, clearly indicate that the gases evolved during combustion do exercise a beneficial effect in generating steam. Since a deficiency of hydrogen may be made up to some extent by introducing water, it is a reasonable deduction, that the practice we have before referred to is consistent with theory.

The last two columns of the table show the practical, mechanical, and theoretical value of 1 lb. of the respective fuels. It is based on Mr. Joule's estimate, that the mechanical value of air and of heat equal to raise 1 lb. of water 1° Fah., is 782 lbs. The application is simply by multiplying the number of pounds of water evaporated by the heat of evaporization, in these cases 965·7° and by 782 for the total value. It is, however, right to state that others take only 682 as the mechanical equivalent of an unit of heat.

Taking the Mynydd Newydd as an example, whose practical value is 9·52 lbs., it gives $9 \cdot 52 \times 965 \cdot 7 \times 782 = 7{,}189{,}288$ lbs., raised 1 foot high. The theoretical value is obtained in a similar manner by taking the ratio of 9·831, instead of 9·52.

Heating of the Feed-water.

It is not unusual to find a very high value placed upon this practice, by those who have not fully investigated the matter. The last two examples show that in the one case it added 1·69, and in the second case 1·78 lbs. to the evaporative value of the fuel, when the water was heated to 212°. The mistake arises from supposing that only 212° of heat are required to evaporate steam of atmospheric pressure, whilst by Regnault's careful experiments it requires 965·7° + 212 = 1177·7°. From this is to be deducted the initial temperature of the water, which if taken at 52° leaves 1125·7° to be imparted in order to convert that water into steam. Hence,

$$\frac{1125 \cdot 7}{212-52} = 7 \cdot 04 \text{ or } 14 \cdot 19 \text{ per cent.}$$

as the utmost gain. If less than the boiling temperature is attained by such heating then the gain would be proportionally decreased, as shown in the following table:—

TABLE No. 31.

Ratio of the Heat applied to Feed-water to the total Heat of Steam of Atmospheric Pressure, or 1177·7° *less the Initial Heat of the Water, or say* 52° *Temperature* = 1125·70.

Water heated from 52° to Fah.	Increase in deg. Fah.	Increase per cent. of the heat of Steam.
62	10	·887
72	20	1·77
82	30	2·66
92	40	3·54
102	50	4·43
112	60	5·32
122	70	6·20
132	80	7·09
142	90	7·98
152	100	8·87
162	110	9·75
172	120	10·64
182	130	11·53
192	140	12·41
202	150	13·30
212	160	14·19

SECTION II.

CHAPTER I.

VARIETIES OF STEAM.

In its general acceptation, steam is pure water expanded by heat into an invisible vapour, but as water is rarely found pure, the heat which distils it into steam also deposits these impurities. Under the influence of solar heat these deposits are familiar in the immense deltas constantly forming at the mouths of rivers; and under the influence of ordinary heat, they are familiar in the "fur" deposited in tea kettles, and incrustations in steam boilers.

There are several distinct varieties of steam recognised, of which we may enumerate,

I. Natural steam, raised by solar heat.

II. Spheroidal steam, raised by dropping water on hot metallic surfaces.

III. Surcharged steam, raised by heating common steam when not in contact with water.

IV. Common steam, raised by ordinary heat.

Natural Steam.

Natural steam is that raised from the various accumulations of water on the earth by solar heat, and is believed to be perfectly analogous to common steam. In a fine day, when solar heat raises natural steam most abundantly it is invisible, so likewise with steam generated in a glass bottle over a spirit lamp, until it comes in contact with the atmosphere. Partial condensation then occurs, and it becomes visible in the form of light fleecy clouds. When the atmosphere is saturated with natural steam, a partial condensation begins to operate, and natural steam becomes visible in the form of clouds, whilst its descent in the shape of mist or rain attests its abundance.

Common steam also assists us to arrive at the probable cause of the beautiful colours which occasionally adorn the floating clouds to the delight of the spectator.

Professor Forbes, having accidentally observed that the steam issuing from a locomotive safety valve changed colour when seen between the observer and the sun, made a series of experiments on the subject at Glasgow, in 1839, which confirmed his accidental discovery. He first observed that at the immediate edge of the safety valve the issuing steam was invisible, but at a short distance from the edge of the valve it had a red appearance, similar to looking at the sun through smoked glass, or the smoky atmosphere common to large cities in peculiar states of the atmosphere. This redness gradually faded away until the steam resembled the ordinary clouds.

The experiments confirmed the original observation, and led him to conclude, that, to the rays of solar light passing through natural steam in a state of partial condensation, were due the gorgeous colouring of the clouds pleasingly adorning our evening skies, and frequently calling forth the artist's skill in delineating "sunset."

The stupendous operations performed by the Great Creator with natural steam have long arrested the scrutinizing attention of philosophers, geologists, and meteorologists, and are thus referred to by the celebrated musician Haydn, in his Oratorio of the Creation, as among the leading phenomena of nature—

"Now from the floods the STEAMS ascend to form reviving showers,
The desolating hail, the light, the fleecy snow.
* * * * *
Ye mighty elements, by whose power
Are ceaseless changes made:
Ye mists and vapours that now rise
From hill or STEAMING lake."

The mighty influence, therefore, of solar heat in raising steam from rivers, lakes, and oceans, to be condensed by the cold of the upper regions, and return to the earth again in rain, hail, or snow, becomes obvious in the succession of atmospheric changes.

Natural evaporation is also greatly influenced by the motion of the air, as shown in the following experimental table by Dalton, giving the evaporation from a vessel 6 inches in diameter, exposed to the atmosphere.

TABLE No. 32.

RATE OF NATURAL EVAPORATION OF WATER.

Temp.	In. Mer.	Calm. Grains.	Gentle Breeze. Grains.	Brisk Wind. Grains.
40	·263	1·05	1·35	1·65
42	·283	1·13	1·45	1·78
44	·305	1·22	1·57	1·92
46	·327	1·31	1·68	2·06
48	·351	1·40	1·80	2·20
50	·375	1·50	1·92	2·36
52	·401	1·60	2·06	2·51
54	·429	1·71	2·20	2·69
56	·458	1·83	2·35	2·83
58	·490	1·96	2·52	3·08
60	·524	2·10	2·70	3·30

Ordinary evaporation is also increased by the quantity of vapour in the air, which increase may be thus determined: Ascertain the dew point, or that temperature when the vapour in the air will begin to condense on a colder body, such as a glass containing a cooling mixture. As soon as this dew or condensing point of the natural steam in the air is found, say at 42°, and the temperature of the air at rest is 58°, the natural steam in the air would be 1·96 by the table, from which deduct the vapour for the dew point of 42° = 1·13, leaving ·83 grains per minute as the ratio of evaporation from a surface of very nearly 29 square inches. The following is one of Daniell's experiments on this point:

The temperature of a room was 45° and the dew point 39°, when a fire was lighted until the temperature rose to 55°, but the dew point remained the same. A party of eight persons then occupied the room for several hours with the fire kept up, when the temperature rose to 58° and the dew point to 52°, hence a considerable accumulation of vapour had taken place, which should have been carried off if the apartment had been properly ventilated. By these simple means the relative states of the air of a room may be ascertained and improved.

Some definite idea will be formed of the magnitude of natural evaporation when it is considered, that it must necessarily be equal to the total supplies of water from all sources, or otherwise another deluge would result from a lesser evaporation.

The Mississippi is estimated to supply 1,110,600 millions of cubic feet of water annually, and to deposit unevaporable matter equal to $\frac{1}{3000}$ of its volume, or 3702 millions of cubic feet. The Ganges is estimated to deposit unevaporable matter equal to 6,000,000 cubic feet, or 355,000,000 of tons annually. Other rivers and streams are also daily carrying the crust of the present earth to the ocean, in greater or lesser quantities, leading to the opinion that in the lapse of time the present relative position of dry land and water will be changed, when the Bucklands, the Lyells, and the Mantells of other ages will be investigating the geological character of the present deposits. That this idea is not without a reasonable basis may be inferred, since the existing delta and plain formed by the deposit of the Mississippi forms an area of 31,200 square miles, or nearly as large as Ireland, which contains 32,512 square miles of surface.

Such is an outline of nature's operations with steam, compared to which the greatest efforts of man—however considerable in his sphere—are small indeed, but the vast difference is not more striking than instructive to mankind.

Spheroidal Steam.

About 1844 this variety of steam was introduced in France by M. Boutigny, and brought into practice by M. Beauregard, who patented its use in this country in 1848. Although it is not probable that it will come in competition with ordinary steam, either for economy or usefulness, considerable notice was taken of it at the time. It is produced by dropping water in a red-hot metal plate, having an indented surface to prevent its running off the plate. When the water is about 206° temperature it adheres to the plate, and slowly passes off into steam; it is said of the elasticity due to the temperature of the plate, and not of the water, and this difference of elasticity is the source of the economy claimed by M. Beauregard for his spheroidal steam generators. When the water is of a higher temperature than about 206°, the repellent power of the heat of the plate and sphere of water prevent their contact, and, as may have been seen when a drop of water has fallen on a hot plate, it runs about growing less and less until it disappears altogether, without being converted into steam. It was estimated that by this generator the water passed into steam about fifty times slower than by an ordinary boiler, but possessing a force which requires only about one per cent. of the space. The spheroidal generator was tried with a vessel of melted lead, heated to 540°, having a hemispherically indented platinum bottom plate, on which the water was thrown from a suitable pipe. The results were said to be more economical than with ordinary steam, but this may reasonably be doubted, since it is the real economy of ordinary steam which enables and will still enable it to compete with many ingenious productions of motive power, where greater expense prevents their realization in practice. Carbonic-acid gas, air, and other motive agents, can and have been found to be capable of developing great power, but have failed as yet to be so economical as steam, and have fallen into disuse from that cause.

Heated Steam or Stame.

More recently Mr. Frost, of America, has called attention to the much greater economy of steam when heated between the boiler and cylinder, than when used in the ordinary way. This heated steam he calls "stame," and contends that it is a different vapour produced by different atomic proportions of heat and water than form ordinary steam. Like M. Beauregard he also estimates the comparative economy as about 4 to 1 in favour of stame. A short description of his instructive experiments may lead to their further investigation.

Fig. No. 25 is a bent glass tube closed at the short end, which contains one drop of water at A. Mercury is then admitted to fill the short end, and a part of the long end of the tube containing a float and index, *a*. The pressure on the drop of water was, therefore, the atmosphere and the mercury in the tube. After being carefully prepared, this eudiometer was placed in cold water, which was gradually made to boil at 212°, and then slowly saturated with salt till the boiling point was stationary at 228°; the ex-

Fig. 25.

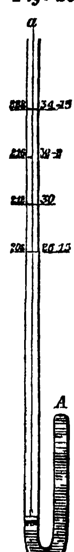


Fig. 26.

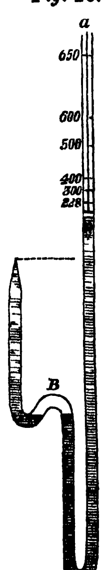
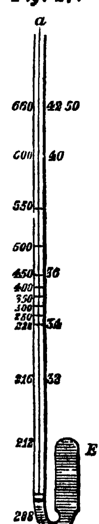


Fig. 27.



pansion being marked, as seen in the diagram at the respective temperatures of the two boiling points.

Fig. No. 26 is a tube of a different form, where the drop of water was confined at the bend B, between two columns of mercury. The short end was closed, and the long end open. It was then subjected as before to boiling at 228° to determine that volume, and then transferred to a mercurical bath, which was gradually heated to 650°. The float and index marked the volume and the pressure in inches of mercury, whilst a thermometer marked the temperature of the bath as it slowly cooled down again. These were carefully noted, and showed much irregularity in the rate of expansion, as marked in the diagram.

Fig. No. 27 is a repetition of the same experiment in a different tube, having a drop of water at the extremity of the bulbous end E. The expansion was carefully marked at 212° to obtain the atmospheric volume, and it was then transferred to the bath as before, when the cooling showed a similar irregularity of expansion as the former experiment. These experiments show the rate of expansion of steam in contact with mercury from 212° to 650°, but not in contact with any water. Similar experiments were performed with the same tubes, but using fusible metal and linseed oil to confine the steam, when the rate of expansion was much more uniform, while nearly the same at the extreme pressures. Taking the difference in the specific gravities of the mercury, fusible metal and oil, the extreme differences may be considered as due to the difference of pressures.

From these experiments it appears that the mercury exercised an influence on the rate of expansion by equal increments of heat, not done by the metal or oil. But what more particularly requires to be noticed and further tested is the great increase of volume by increase of heat, with a slow increase of elastic force. For whilst the elastic force only increased 12·5 inches of mercury, the volume was increased to seven times that of 212°, making a total volume eight times greater than the atmospheric volume of ordinary steam.

It has been usual to treat steam as subject to the same laws as air, which expands ·00202, or $\frac{1}{480}$ of its volume for each increase of one degree of Fahr., but these experiments show an increase of seven volumes for an increase of only 438° of heat.

If further carefully conducted experiments confirm these results, then Gay Lussac's law for permanent gases is not adapted for heated or surcharged steam. As that law purports to commence at 32° when the volume of water is 1, which at 212° becomes suddenly 1700 times that volume, Gay Lussac's law has been applied to steam, through the 1700 volume, and correction of 180° temperature, so that its failure in steam—if failure it prove, may not affect its application to permanent gases, for which it was submitted. The probability that the variation in the respective states of water at 32°, 40°, and 212°, known as ice, water and steam, may in stame not perhaps be governed by a law designed for permanent gases, cannot be remarked without reflections on the Author of that law.

Fig. 28.

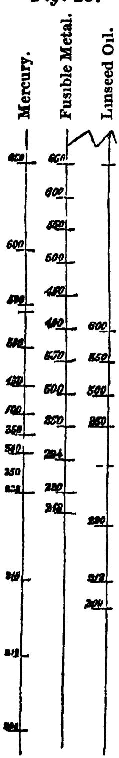
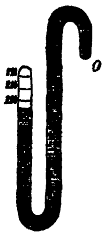


Diagram No. 28 shows the results of these experiments collected on a scale of equal parts. The metal was bismuth 5, lead 3, and tin 2, which is fusible at 210°, but on cooling it lost its fluidity so far at 218° as not to be depended upon below that temperature.

To test in another way the influence of the pressure of bodies on the generation of steam, when in contact with these bodies, the following experiments were tried:

The glass eudiometer, Fig. 29, was filled with boiling water and heated in a bath at 650°, when all the water was expelled, and its open end *o* her-

Fig. 29.



metically sealed, leaving only the water due to the steam in the tube. This being condensed, left a vacuum, and the tube being immersed in a vessel of mercury, the sealed end was broken off, when of course the mercury instantly filled the vacuum. On being subjected to heat, the steam showed itself at the usual temperatures. The same process was repeated with turpentine, but up to its boiling point of 316° no steam appeared. Also with linseed oil, no steam showed itself up to 400° temperature.

These experiments indicate that whilst mercury exercises no great influence over minute portions of water passing into steam, yet both turpentine and linseed oil do so to a great extent. The fixity of water when subjected to high temperatures, as exemplified in the spheroidal generator, was tested by introducing a small drop of water about one inch below the surface of the linseed oil, with which water does not combine. The glass tube was then slowly heated to 300° but the water remained unevaporated. At 320° it began to decrepitate, and at 340° the concussions led to the close of the experiment to save the tube from being broken, when one-half of the drop of water still remained. Since linseed oil is lighter than water, as ·93 to 1, the pressure was less than that of an equal column of water, through which steam rises with rapidity, yet the temperature was equal to that of ordinary steam at 116 lbs. per square inch. To test the results of these experiments practically, two engines, one having a three-inch, and the other a six-inch piston, giving the respective areas as one to four, were tried publicly, and showed a corresponding gain in favour of *stame* over *steam*. They were both supplied with steam from the same boiler, generated by equal quantities of fuel, consumed in equal times. The only difference was, that the steam pipe to the large cylinder was carried through the upper part of the furnace in a spiral tube, having a heating area of about $\frac{1}{5}$ that of the boiler. Measured by one of Morin's Dynameters the power given out was four times greater from the larger than from the smaller cylinder, indicating that the pressure on both cylinders was nearly alike, and that the increase *of volume* was due to the heat taken up by the steam in passing through the furnace. If this is a fair estimate of the difference, it shows that there is a considerable gain at a small cost; and that of the theoretical expansion of eight volumes, four were realized in practice, whilst the remainder filled the extra pipes and balanced the abstraction of heat again by colder bodies and other resistances.

Mr. Frost gives the following comparison of steam and stame, with the effects of the exhausted steam, in baking bread from dough:

Pressure.		Temperature in			Effects on Dough.	
——	Atmos.	Boiler.	Cylinder.	Exhaust pipe	Surface.	Substance.
Steam	6·5	321°		216°	Glistening.	Tender.
Stame	2·5	264°	612°	550°	Charred.	Hard.

This is probably an extreme result, giving 612—550, a loss of only 62°. For stame is found to take up and part with heat rapidly to colder bodies, requiring the temperature of the conducting pipe and cylinder to be maintained when the heated steam was six times as effective as ordinary steam, although passed through a coil of piping ten times the length of the ordinary steam pipe.

From experiments made in France, it is stated that steam heated to 392° does not char wood, that at 482° it is imperfectly charred, at 572° it is charred brown, and at 662° it makes black charcoal, yielding a greater quantity and better quality of charcoal for making gunpowder than by the ordinary process of charring.

The French Minister of War advanced 5000 francs for carrying out these experiments, which led to its adoption for making the charcoal at the Esquinede gunpowder mills. The experiments were made similarly to M. Frost's, by heating ordinary steam in a coil of pipe 8 inches diameter, and 66 feet long. M. Violette states, that at 392° bread can be baked, meat cooked, and other extractive operations successfully accomplished by stame, for we prefer the more simple name to any compound of surcharged, heated, or anhydrous steam, by all of which names it is occasionally designated.

At Stonehouse, Plymouth, Mr. Lee's patent oven is said to bake superior bread in an atmosphere of stame whose heat is regulated by a thermometer. To numerous visitors of the Crystal Palace, Mr. Perkins, of London, distributed pieces of bread baked in his patent "hot water" or stame oven, by the radiation of the heat through coils of pipes forming shelves for the loaves.

The importance of stame is, therefore, not confined to its operations in the steam engine, but extends over a wider field. In America, Frost's experiments drew the attention of the Institute of Arts and Sciences at New York, who give the following tabular results of experiments: The steam was got up to 21 lbs. pressure, and the engine made 2000 revolutions, which exhausted the steam in the boiler, and the condensed steam raised the temperature of the condensing water from 48° to 62°, or 14°. With the same pressure in the boiler, but heated in passing to the cylinders, when the engine had made 2000 revolutions by stame the pressure in the boiler was raised to 37 lbs., and the water in the condenser from 61° to 70°, or 9°. During the trials the condenser showed a steady vacuum of 12 lbs. For equal volumes, therefore, it appears that the heat was greater in steam than in stame in the ratio of the heat communicated to the condenser, or as 14 to 9; and that the less abstraction of heat from the boiler by stame, added the difference between 21 and 37, or 16 lbs. effective pressure to the steam in the boiler, whilst with ordinary steam the heat was all expended and could not sustain the pressure.

Table No. 33.

EXPERIMENTS ON STAME BY THE COMMITTEE OF THE ARTS AND SCIENCES INSTITUTE, NEW YORK.

At Low Pressure.

Temp. Fah.	Vol. In. mer.	Pressure. In. mer.	Actual volume of stame each.
31	0·1	0·2	0·1
94	1·	2	2·
115	2	4	8
128	3	6	18
138	4	8	32
150	5	10	50
159	6	12	72
165	7	14	98
172	8	16	128
180	9	18	162
212	10	20	200

At High Pressure.

Temp. Fah.	Vol.	In. mer.	Pressure.	
			Atmospheric.	In a given vol. In. mer.
212	1	30	1	30
216	2	32	2·133	64
228	3	34	3·4	102
450	4	36	4·8	144
600	6	40	7·2	216
650	7·37	42·75	9·8	294

The committee felt satisfied of the importance of these experiments, and of the economy of stame if it could be brought into operation, where the temperature of colder bodies would not interfere to abstract the heat before it could be profitably employed.

Dr. Haycraft, of Greenwich, had also made a number of experiments with stame, or, as he designates it, anhydrous steam, and freely criticized Frost's mode of conducting his experiments as liable to error, at the same time giving instances where he had himself been deceived in the results of practice, as compared with the results of experiments. He tried his plan on an engine having a 9-inch cylinder, and 3-feet stroke, which worked very economically, but he found that the pipes subjected to the heat gave way, and in the aggregate did not realize what he expected. He then employed a steam jacket, and a vessel for separating the steam from any unevaporated water, and realized in a large engine 25 per cent. by the separation, and 46 per cent. economy where both steam jacket and separation were used. These experiments were made before Mr. Wright, the Government Comptroller and Inspector of Steam Machinery. Although Dr. Haycraft differs with Frost on some of the details of the experiments, he yet fully admits the economy of stame to be very nearly as great as it is estimated by Frost.

The ease with which stame could be tested fully in inside cylinder locomotives, and its admitted economy, have led us to give this abstract of Frost's experiments, and the opinions of those who have criticized them, as a subject capable of further investigation at a nominal cost. A coiled steam-pipe in the smoke-box end, where the temperature of the escaping gases is always high, would soon indicate its value in locomotive engines, where, if successful, a further reduction in the quantity of fuel consumed would be effected.

CHAPTER II.

Common Steam.

By combining heat and water together in a close vessel steam is produced, and as a well-known elastic motive agent it has become quite a household word. To the hardy miner in developing the treasures of the earth, to the skilful manufacturer in giving form to his fabrics, to the adventurous mariner in traversing the ocean, and to the traveller in rivalling the eagle's speed, steam has alike lent its potent aid, and now displays its agents and its triumphs in the Crystal Palace.

Thus to the fullest extent has been realized the prediction of Sir Samuel Morland in 1682, that steam might be harnessed to duty like a quiet horse. Even in the field of locomotion, where the muscular energies of that noble animal seemed to defy mechanical competitors, steam has won some of its greatest triumphs, and extended its usefulness.

The following properties of steam now claim our attention:

I. Its Elastic Force.
II. Its Mechanical Force.
III. Its Temperature.
IV. Its Volume.
V. Its Velocity.
VI. Its Expansive Force.
VII. Its Practical Force.

1st. Elastic Force of Steam.

An elastic body is one which presses equally in every direction, whilst admitting of being compressed into a smaller or expanded into a larger space, with the power of returning to its original space when restored to its original conditions again. Water, it has been seen, is almost incompressible, and is therefore a non-elastic body. Air, it has been shown, is compressible, and consequently is an elastic body. As water is made the standard of the specific gravities or weights of heavy bodies, so is air made the standard for gaseous elastic bodies, and its laws are usually applied to illustrate the elasticity of steam in contact with water. Besides possessing elastic properties similar to air, steam possesses the additional and valuable one of being easily condensed by cold to water again. In applying the acknowledged laws of air to steam, they only apply when the steam receives its heat from the water and remains in contact with it, maintaining the given temperature increased or diminished only by the space it occupies. The numerous indicator cards taken from cylinders show that these laws are nearly correct for low-pressure steam; but that for high-pressure steam the curve of expansion is fuller than the theoretical or hyberbolic curve, indicating a greater continuation of force from a less rapid abstraction of heat than is assigned by these laws. Where locomotive engines have inside cylinders fixed in the hot-smoke box, this fuller curve is probably due to the high temperature imparting a slightly stame character to the isolated steam, but influenced by the velocity of the piston and heat on the smoke box. For all ordinary pressures and temperatures of steam in contact with wâter, the following laws of elastic fluids will practically explain the expansive property of steam. We find, however, that these laws and the practical application of steam to railway locomotion must be deferred to the Second Part, where they will be illustrated and fully explained in a popular manner.

ELEMENTARY TREATISE

ON

STEAM AND LOCOMOTION;

BASED ON THE PRINCIPLE OF

CONNECTING SCIENCE WITH PRACTICE,
IN A POPULAR FORM.

With Illustrations.

BY

JOHN SEWELL, L.E

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A TREATISE

ON

STEAM AND LOCOMOTION.

PART II.

CHAPTER I.

PRESSURE OF AIR AND ELASTIC FLUIDS.

UNTIL near the middle of the seventeenth century it was not even suspected that the air possessed either weight or elastic force. Pumps, being an earlier invention of Ctesibus, had come into general use for raising water, and practical men had noted the fact that water rose far above its natural level in the pump tube, when the working valve, or bucket, had withdrawn the air from that part of the tube. Philosophers explained this as a proof of nature's abhorrence of a vacuum, which caused the water to fill the vacuum in the pump tube, and in fixing them this was taken advantage of by placing the working valves where most convenient. However, a pump having been erected at Florence for the Duke of Tuscany, it failed to raise any water, and its failure was a very unexpected result. It was then ascertained that the water was above 33 feet distant from the pump valve, and only rose to about that height, but not within the action of the pump, hence the cause of the failure was apparent, but not so the limit thus assigned to Nature's abhorrence of a vacuum. Galileo was consulted, but was unable to give any valid reason for this limit at the time. Reflection, however, led him to conclude that the air had weight, and that the weight pressing on the water caused it to rise. Following out this reasoning, his pupil Torricelli had the honour to construct the first barometer, and to determine by experiment the relative weight and pressure of air.

As barometers are applied to measure the pressure of steam as well as that of air, a description of them will be instructive.

Fig. 30.

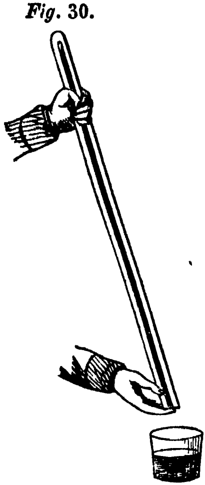


Fig. 31.

Fig. 32.

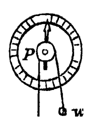


Fig. No. 30 or 31 is a glass tube about 36 inches long, closed at one end, which Torricelli filled with mercury, carefully excluding the air. Then applying his finger to the open end, he inverted the tube with its open end in a cup containing both water and mercury. He then withdrew his finger while the tube end was immersed amongst the mercury, when it flowed out until it became stationary at a height of about thirty inches. When the end of the tube was raised out of the mercury, and open to the water, the mercury flowed out, whilst the water rushed in to the top of the tube, showing that it would have risen still higher, had the tube been longer. These simple yet beautifully important experiments clearly demonstrated that the pressure of the air was equal to the pressure of a column of mercury thirty inches high, or to a column of water of an equal pressure.

The specific weight of mercury varies according to its purity and temperature, but in ordinary circumstances it is about 13·6 times heavier than water, hence the height of a column of water equal to the weight of a column of mercury 30 inches high, would be 30 × 13·6 ÷ 12 in. = 34 feet, which water would rise in a perfect vacuum by the pressure of the air on its surface. This, therefore, proved that the water would rise to a height in the pump tube more or less near to 34 feet, as the vacuum was more or less perfect, but beyond 34 feet the pressure of the air would fail to raise the water, thereby solving the pump problem in the most satisfactory manner. Since a cubic foot of water is nearly and usually taken as 1000 ounces avoirdupois, a cubic foot of mercury would be 1000 × 13·6 = 13,600 ounces, and one inch of mercury would be 13,600 ÷ 1728 = 7·87 ounces, therefore 30 × 7·87 ÷ 16 ounces = 14·75 lbs. as the elastic force of the air at the level of the sea. In round numbers it is usual to consider the pressure of the air as equal to 15 lbs. on each square inch, which is called the pressure of one atmosphere, 30 lbs. being that of two atmospheres, 45 lbs. that of three atmospheres, and so on with each additional 15 lbs. It will illustrate the pressure of elastic fluids in every direction, when it is stated that the pressure of air on the body of an average-sized man amounts to about 15 tons, which of course would instantly crush him to the earth, were it not counteracted by its equality of pressure in every direction, upwards, sidewards, downwards, internally and externally. Its weight is about 820 times lighter than water, (or ·00122,) as determined by M. Arago. The elastic force of air on a square foot of surface would amount to 144 × 14·75 lbs. = 2124 lbs., but the weight of 144 cubic inches would only be ·00669 lbs. or nearly 31·72 times less weight than pressure. This greater pressure is due to the superincumbent column of air estimated by some as from 45 to 50 miles high, but by others as not even so high as 40 miles.

Air has, therefore, both weight and force pressing in every direction, in the ratio of 2124 lbs. per square foot of surface, yet in it we live, move and breathe, as if it had neither weight nor force. Many attempts have been made to bring the elastic force of the atmosphere into mechanical use like steam. The Croydon and South Devon Atmospheric Railways now abandoned, and Prosser's compressed air engine now in the great exhibition, are recent instances of these efforts, but as yet they have been unable to compete with steam in portability and economy.

To the feelings the changing pressure of the air seems reversed to what it really is, for on a fine dry day the air is heaviest, causing the mercury to rise, and on or before a wet day it is lightest, allowing the mercury to flow out of the tube or fall. Yet on a fine day the feelings are buoyant, and on a wet day depressed. This is easily accounted for.

Natural steam is only about one half or five eighths the weight of an equal volume of air, hence when the air becomes saturated with natural steam it is of course lighter, and in an equal volume contains less oxygen. When the natural steam has fallen in the form of rain or snow, the air becomes heavier from its containing more oxygen in an equal volume, for oxygen is 1·11 times heavier than the mixture of $\frac{4}{5}$ nitrogen and $\frac{1}{5}$ oxygen, which constitutes the atmosphere. The more oxygen inhaled the more buoyant and elastic are the feelings, hence as the barometer tells by rising, so the lungs also by expanding, that more oxygen is present; and as the barometer indicates by falling that steam has displaced a portion of the oxygen, so likewise does the collapsion of the lungs truly indicate the absence of the life-supporting oxygen. Whilst, therefore, the barometer weighs the exact pressure of the air, the lungs also tell us its life-supporting power with much fidelity.

Fig. No. 32 is the modern form of barometer for halls, where the float is suspended by a fine line over the small pulley *p*, and balanced by a weight *w*; and as the pulley is moved by the action of the float *f*, the indications by the index *i* are read off on a large dial, D.

As we ascend upwards the pressure of the air diminishes, and by this means the barometer is employed to measure the heights of mountains and other elevated places with considerable accuracy, by the fall of the mercury. Pascal first applied it to this purpose; but as the pressure of the air diminishes by increase of temperature, as well as by increase of height, and its density increases by cold, it requires a scale graduated accordingly. For example, a decrease of 1° of temperature increases the density or pressure of the air ·0033 inches of mercury between the limits of 32° and 52°; but from 32° down to zero the mercury falls ·0034 for each difference of 1° of temperature. At an elevation of 500 feet the mercury falls half an inch; but at 31 times 500 ft. high, it only falls 28 half inches, and at 41 times 500 ft. high only 36 half inches.

The following rule gives the heights of places nearly :—

Multiply the difference of the logarithms of the respective barometric heights by 6000 for the height above the level of the sea in feet.

Ex. Required the elevation of a hill at whose base the height of the mercury was 30 inches, and at the top 28 inches,

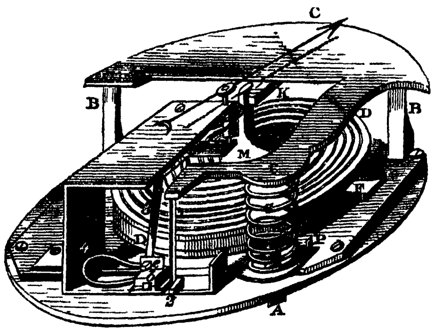
log. 30 = 477121
log. 28 = 447158

Difference = 029963 × 6000 = 1797·78 feet as the height required.

To obtain a more portable and sensitive barometer for such measurements than the mercurial one, a vacuum barometer of ingenious yet comparatively complicated construction has been brought to considerable perfection in France, since M. Conte first introduced it. As now improved by Mr. Dent, of London, it is a portable, and as it may be an agreeable companion to railway travellers for determining the comparative elevation of the countries or railways that they travel over, we annex a brief description of its principle of action.

The same letters apply to all the figures.

Dent's Aneroid Barometer.—Fig. 33.



In Fig. No. 33, D D is the vacuum vase. M, the socket for distending it. C C is a lever, to one end of which is attached the vertical rod, 1, which connects it with the levers, 2, 3. These levers are connected by a bowpiece, 4, and the whole are regulated for the index to move over a space corresponding to the scale of a mercurial barometer. The end of lever 3 is connected to the axes, on which the hand or index is fixed by a piece of fine watch chain. A spiral spring regulates the hand, and the force of the levers in obedience to the indication of the vacuum vase D D, as distended Fig. No. 34, and compressed, Fig. No. 35, by the weight of the atmosphere.

Fig. 34.

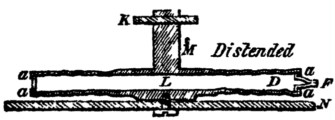
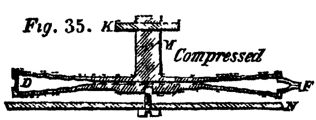


Fig. 35.



Front Elevation.—Fig. 36.

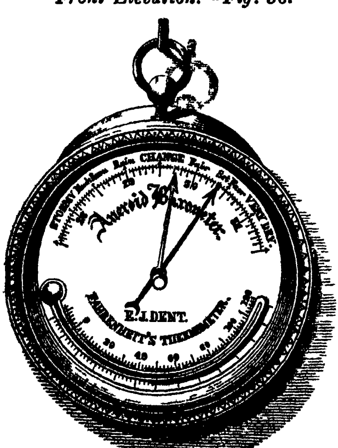


Fig. No. 36, exhibits a front view of this ingenious instrument, and indication hand. W, the index of comparison, to be set exactly over the hand *b*, at the commencement of any experiment. The movement of the hand O to either the right or the left will then indicate the increase or decrease of the atmospheric pressure.

Diagram showing Principle of Action.—Fig. 37.

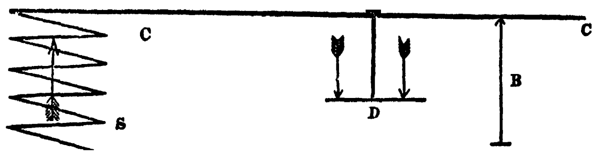


Fig. No. 37, will explain the principle of action. C C is a lever of the second order, similar to a locomotive safety-valve lever, which has its fulcrum at B and its force measured by the spiral spring S. The vacuum vase is attached to the lever C C at D, one-seventh of the distance between B and S. It is 2½ inches diameter, having about 72 lbs. pressure on its area, whose action on the lever C at D, as represented by the arrows, is 6 times increased on the spring S, the lever being as 6 to 1, or 7 parts in all. This it is obvious renders the least variation of pressure quite sensible by the spring when the friction of the parts is reduced to a minimum. In Dent's the motion of the index-hand one-tenth of an inch indicates an alteration of either 85 feet higher or lower, as the case may be. The action of a barometer is therefore regulated by the weight of the air, which is heaviest during serene settled or frosty weather, or when contrary easterly or northerly winds blow it towards any locality. It is lightest when saturated with steam to the rainy point, or when contrary winds blow it away from any locality. In northerly climates the variation is greatest, and least within the tropics.

Several lengthened trials against the best mercurial barometers indicate that the vacuum barometer may be relied on for all ordinary purposes; and the following table will supply the means of ascertaining the comparative gradients of a railway by one of them.

Table No. 34.

BAROMETRIC TABLE.

Barometric Height.	Atmospheric Height.	Proportional 1000th parts to be added as required.	Barometric Height.	Atmospheric Height.	Proportional 100th parts to be added as required	Barometric Height.	Atmospheric Height.	Proportional 1000th parts to be added as required.
In Mer	Feet.		In Mer	Feet		In Mer	Feet	
28·00	27425·3	+	28 30	27703·7	+	28 60	27979·2	+
1	27434·6	0·9	1	27712·9	0 9	1	27988·3	0·9
2	27444·0	1·9	2	27722·2	1 8	2	27997·5	1·8
3	27453·3	2·8	3	27731·4	2·8	3	28006·6	2·7
4	27462 6	3·7	4	27740 6	3·7	4	28015·7	3·7
5	27471·9	4·7	5	27749·8	4·6	5	28024·8	4·6
6	27481·3	5·6	6	27759 1	5·5	6	28034·0	5·5
7	27490·6	6·5	7	27768·3	6 5	7	28043·1	6·4
8	27499·9	7·5	8	27777·5	7·4	8	28052·2	7·3
9	27509·2	8·4	9	27786·7	8 3	9	28061·3	8·2
28·10	27518·4	+	28·40	27795·8	+	28·70	28070·5	+
1	27527·7	0·9	1	27805·0	0·9	1	28079·6	0·9
2	27537·0	1·9	2	27814·2	1·8	2	28088·7	1·8
3	27546·3	2·8	3	27823 4	2·8	3	28097·8	2·7
4	27555·6	3·7	4	27832 6	3·7	4	28106·9	3·6
5	27564·9	4·6	5	27841·8	4·6	5	28115·9	4·5
6	27574·2	5·6	6	27851 0	5 5	6	28125·0	5·5
7	27583·5	6·5	7	27860·2	6·4	7	28134·1	6·4
8	27592·7	7·4	8	27869·3	7·4	8	28143·2	7·3
9	27602·0	8·4	9	27878·5	8·3	9	28152·2	8·2
28·20	27611·3	+	28·50	27887·7	+	28·80	28161·3	+
1	27620·6	0·9	1	27896·9	0 9	1	28170·4	0·9
2	27629·8	1·9	2	27906 0	1 8	2	28179·4	1·8
3	27639·1	2·8	3	27915·2	2·7	3	28188·5	2·7
4	27648·3	3·7	4	27924·3	3·7	4	28197·5	3·6
5	27657·6	4·6	5	27933·5	4 6	5	28206 6	4·5
6	27666·8	5·6	6	27942·6	5·5	6	28215·6	5·4
7	27676·1	6·5	7	27951·8	6·4	7	28224·7	6·3
8	27685·3	7·4	8	27960·9	7·3	8	28233·7	7·2
9	27690·6	8·3	9	27970·1	8 2	9	28242·8	7·1

* Being an extract, by permission, from the elaborate table of W. Galbraith, M.A., dedicated to Sir Thomas M. Brisbane, Bart.

Barometric Height.	Atmospheric Height.	Proportional 1000th parts to be added as required.	Barometric Height.	Atmospheric Height.	Proportional 1000th parts to be added as required.	Barometric Height.	Atmospheric Height.	Proportional 1000th parts to be added as required.
In. Mer.	Feet.		In. Mer.	Feet.		In. Mer.	Feet.	
28·90	28251·8	+	29·30	28611·1	+	29·70	28965·2	+
1	28260·8	0·9	1	28620·0	0·9	1	28974·0	0·9
2	28269·9	1·8	2	28628·9	1·8	2	28982·8	1·8
3	28278·9	2·7	3	28637·8	2·7	3	28991·6	2·6
4	28287·9	3·6	4	28646·7	3·6	4	29000·4	3·5
5	28296·9	4·5	5	28655·6	4·5	5	29009·1	4·4
6	28306·0	5·4	6	28664·5	5·3	6	29017·9	5·3
7	28315·0	6·3	7	28673·4	6·2	7	29026·7	6·1
8	28324·0	7·2	8	28682·3	7·1	8	29035·5	7·0
9	28333·0	8·1	9	28691·2	8·0	9	29044·2	7·9
29·00	28342·1	+	29·40	28700·0	+	29·80	29053·1	+
1	28351·1	0·9	1	28708·9	0·9	1	29061·9	0·9
2	28360·1	1·8	2	28717·8	1·8	2	29070·6	1·8
3	28369·1	2·7	3	28726·6	2·7	3	29079·4	2·6
4	28378·1	3·6	4	28735·5	3·6	4	29088·1	3·5
5	28387·1	4·5	5	28744·4	4·4	5	29096·9	4·4
6	28396·1	5·4	6	28753·3	5·3	6	29105·6	5·3
7	28405·0	6·3	7	28762·1	6·2	7	29114·4	6·1
8	28414·0	7·2	8	28771·0	7·1	8	29123·1	7·0
9	28423·0	8·1	9	28779·9	8·0	9	29131·9	7·9
29·10	28432·0	+	29·50	28788·7	+	29·90	29140·6	+
1	28441·0	0·9	1	28797·5	0·9	1	29149·3	0·9
2	28450·0	1 8	2	28806·4	1·8	2	29158·1	1·7
3	28458·9	2·7	3	28815·2	2·7	3	29166·8	2·6
4	28467·9	3·6	4	28824·1	3·5	4	29175·5	3·5
5	28476·9	4·5	5	28832·9	4·4	5	29184·2	4·4
6	28485·8	5·4	6	28841·8	5·3	6	29193·0	5·2
7	28494·8	6·3	7	28850·6	6·2	7	29201·7	6·1
8	28503·8	7·2	8	28859·4	7·1	8	29210·4	7·0
9	28512·7	8·1	9	28868·3	8·0	9	29219·1	7·8
29·20	28521·7	+	29·60	28877·1	+	30·00	29227·8	+
1	28530·6	0·9	1	28885·9	0·9	1	29236·5	0·9
2	28539·6	1·8	2	28894·7	1·8	2	29245·2	1·7
3	28548·5	2·7	3	28903·6	2·7	3	29253·9	2·6
4	28557·5	3·6	4	28912·4	3·5	4	29262·6	3·5
5	28566·4	4·5	5	28921·2	4·4	5	29271·3	4·3
6	28575·4	5·4	6	28930·0	5·3	6	29280·0	5·2
7	28584·3	6·3	7	28938·8	6·2	7	29288·7	6·1
8	28593·2	7·2	8	28947 6	7·1	8	29297·3	7·0
9	28602·2	8·0	9	28956·4	8·0	9	29306·0	7·8

Barometric Height.	Atmospheric Height.	Proportional 1000th parts to be added as required.	Barometric Height.	Atmospheric Height.	Proportional 1000th parts to be added as required.	Barometric Height.	Atmospheric Height.	Proportional 1000th parts to be added as required.
In. Mer.	Feet.		In. Mer.	Feet.		In. Mer.	Feet.	
30·10	29314·7	+	30·40	29573·8	+	30·70	29830·2	+
1	29323·4	0·9	1	29582·4	0·9	1	29838·7	0·9
2	29332·0	1·7	2	29591·0	1·7	2	29847·2	1·7
3	29340·7	2·6	3	29599·6	2·6	3	29855·7	2·5
4	29349·2	3·5	4	29608·2	3·4	4	29864·2	3·4
5	29358·0	4·3	5	29616·7	4·3	5	29872·7	4·3
6	29366·7	5·2	6	29625·3	5·2	6	29881·2	5·1
7	29375·3	6·1	7	29633·9	6·0	7	29889·7	6·0
8	29384·0	6·9	9	29642·5	6·9	8	29898·2	6·8
9	29392·6	7·8	8	29651·0	7·7	9	29906·7	7·7
30·20	29401·3	+	30·50	29659·6	+	30·80	29915·2	+
1	29409·9	0·9	1	29668·1	0·9	1	29923·7	0·8
2	29418·6	1·7	2	29676·7	1·7	2	29932·2	1·7
3	29427·2	2·6	3	29685·2	2·6	3	29940·7	2·5
4	29435·9	3·5	4	29693·8	3·4	4	29949·2	3·4
5	29444·5	4·3	5	29702·3	4·3	5	29957·6	4·2
6	29453·2	5·2	6	29710·9	5·1	6	29966·1	5·1
7	29461·8	6·1	7	29719·4	6·0	7	29974·6	5·9
8	29470·4	6·9	8	29727·9	6·8	8	29983·1	6·8
9	29479·1	7·8	9	29736·5	7·7	9	29991·5	7·6
30·30	29487·7	+	39 60	29745·0	+	30·90	30000·0	+
1	29496·3	0·9	1	29753·5	0·9	1	30008·5	0·8
2	29504·9	1·7	2	29762·1	1·7	2	30016·9	1·7
3	29513·6	2·6	3	29770·6	2·6	3	30025·4	2·5
4	29522·2	3·4	4	29779·1	3·4	4	30033·8	3·4
5	29530·8	4·3	5	29787·6	4·3	5	30042·3	4·2
6	29539·4	5·2	6	29796·2	5·1	6	30050·7	5·1
7	29548·0	6·0	7	29804·7	6·0	7	30059·2	5·9
8	29556·6	6·9	8	29813·2	6·8	8	30067·6	6·8
9	29565·2	7·7	9	29821·7	7·7	9	30076·1	7·6

In this table, the middle column exhibits heights in English feet, corresponding to the height of the barometer, shown in the first column, in inches, tenths, and hundredths; the proportional parts to thousandths are given in the right-hand column.

EXAMPLE.—It is required to find, in English feet, the difference of level between Dover and Folkstone Railway-stations by the barometer, Dover indicating 30·125 inches, and Folkstone 30·000. In the table at 30·12 we find 29332 0, and in the column A at 5 we have 4·3; which, added to 29332·0, gives for Dover 29336·3. On referring to the 30·000 inches in the table, by which Folkstone is indicated, we find 29227·8. The one, subtracted from the other, gives the difference in feet between the two stations:—

Dover	. . . .	29336·3
Folkstone	. . .	29227·8
	Feet .	108·5

Folkestone-station, therefore, is higher than that at Dover by 108·5 feet.

The above experiment was actually made while sitting in a railway-carriage, and the example will serve as a guide for taking any measurement by the barometer.

The natural philosopher is enabled, by means of the Aneroid, to discover the quantity necessary for thermometrical correction. He has only to expose the instrument to the temperature of the external air, (having set the hands in coincidence,) and afterwards place it before the fire, until the thermometer is at 100. Any variation of the hand, divided by the degrees of the thermometer, will give the quantity for each degree. Mr. Dent remarks of this instrument, that the quantity to be allowed for correction does not generally equal what is necessary for the correction of the mercurial barometer. The amount will be sometimes in defect, and at others in excess. So nearly is the Aneroid compensated for varying temperatures.

Mercurial Gauges for Steam Engines.

These useful appendages to the steam engine being either barometrical or thermometrical, this seems the proper place to describe them. Where the length is not a consideration the barometric ones act well, but thermometric ones cannot be depended upon generally.

Fig. 38.

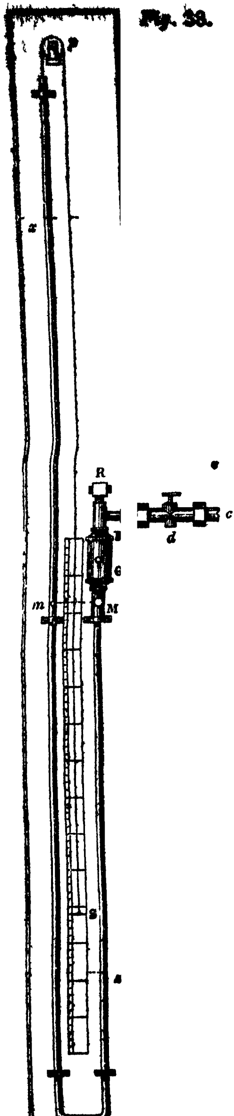


Fig. No. 38, is one of the forms in which mercury is employed to measure the pressure of steam when it is only a few pounds more pressure than that of the atmosphere. Steam is admitted from the boiler by the pipe *c*, and presses the mercury up the iron syphon tube M, *b*, *m*. Each 2 inches of rise is nearly equal to 1 lb. pressure above the atmosphere, which has access to the top of the mercury by the open end of the tube. A line from the float in this tube passes over the pully *p*, and is attached to the index S, to show the variation of pressure on the annexed scale. Gauges of this barometric form require to have a length equal to 2 inches for each pound of pressure, which makes them inconvenient at high pressures. It is thus constructed: M, *m*, R, are 3 openings fitted with suitable screws. These are taken out, and mercury poured in until it shows itself at M *m*, in each leg of the syphon, when these 2 holes are screwed up. Some water is then poured in at R, which is then also screwed up, and the instrument ready for use. The water prevents the heat of the steam oxidizing the mercury, which is found to injure its expansive action, and render its indications erroneous in thermometrical steam gauges.

Fig. 39.

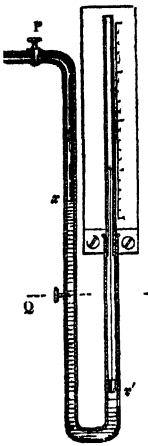


Fig. 40.

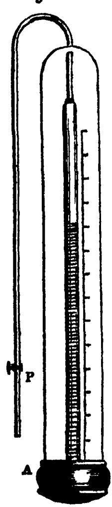


Fig. No. 39, is a different form, where the mercury is all contained in the tube *x x*, which has one end connected to the boiler by the pipe P, and the other end open to the atmosphere. The indications being given off on the attached scale of parts.

Fig. No. 40, is another form of mercurial gauge for condensers. A, a cup filled with mercury, in which the barometric tube is immersed, having the other end bent in the syphon form, and connected with the condenser of a low-pressure engine. On the cock P being opened, the pressure of the air on the mercury in the cup causes it to rise and indicate, on the scale of parts, the comparative vacuum produced in and power gained from the condenser.

In all these gauges the pressures indicated are the differences between the atmospheric pressure and the pressure in the boiler or in the condenser. In condensers the pressure will be less than the atmosphere by 2 inches for each pound pressure. In the boiler, the pressure will be greater than the atmosphere by 2 inches for each pound. So that a rise of 8 inches in the boiler gauge indicates steam of 4 lbs. pressure above the atmosphere, or 19 lbs. gross pressure, and a rise of 24 or 26 inches in the condenser gauge shows that a pressure of 12 or 13 lbs. has been added to the 4 lbs. pressure, making a working pressure of 16 or 17 lbs. per square inch from an apparent pressure of only 4 lbs.

Air Gauge.

Since the preceding gauges require a length of 2 inches of mercury for each pound of pressure, they are inapplicable to pressures of 60 or 100 lbs. on locomotive boilers. In place of leaving the mercury exposed to the air at one end, and to the steam at the other end, air is confined in a Torricellian tube, closed at the upper end, and resting in a cup of mercury at the lower end, on which the force of the steam acts to compress the column of air, which then becomes the measure of the force of steam.

Fig. 41.

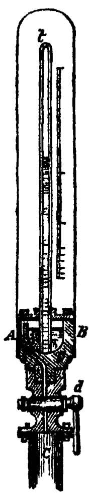


Fig. 42.

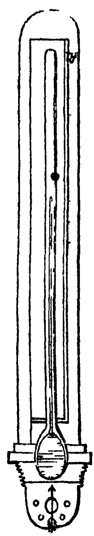
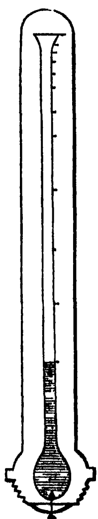


Fig. No. 41, will show their construction. *t t* the glass tube containing air, immersed in the cup A B of mercury, which rises to the level or pressure balanced by the mercury in the cup and the air in the tube, for the zero of the gauge. The volume of a given quantity of air being inversely as the space it occupies, a scale—starting at the gauge zero—is adjusted to this established law, to show the force of the steam by the diminished volume of the confined air. For instance, if the pressure be 20 lbs. and increased to 40 lbs., the volume of air would be reduced one-half, and at 60 lbs. to one-third the volume at 20 lbs., as will be further illustrated under the head of Expansive Force of Elastic Fluids. On steam being admitted by the stopcock *d* it presses upon the mercury in A B, which rises and compresses the air in the tube and indicates the force on the scale. Gauges of this class were employed by both the French Academy and Franklin Institutes in their valuable experiments on steam.

When carefully made and adjusted they are valuable instruments. On locomotive engines the passing current keeps the confined air from heating, which requires to be guarded against, and if the scale is correctly adjusted the indications would be accordingly.

Fig. No. 42, is another form of this useful gauge, where very small holes in the bottom of the bulbous part of the tube admit the direct action of the steam on the mercury, whilst the reservoir at the top gives a larger volume of air to act against, with less risk of error.

Fig. 43.



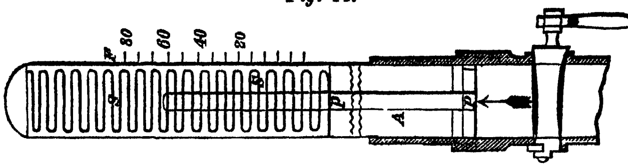
When steam is freely admitted to act on mercury for a length of time, the mercury is found to deteriorate; or the loss of any portion of it from the tube or cup would affect the accuracy of the scale. Mr. Davies of Leeds states that he has, by using a larger column of mercury, greatly improved the accuracy and durability of mercurial steam gauges.

Thermometric gauges (Fig. No. 43) are similarly constructed to those already described for measuring heat by, and are designed to give the force of steam from its temperature. They have not yet, however, been successful for accuracy of indications. If the heat communicated to the bulb is partly lost in the ascent of the mercury, the upper portion would not equally expand with the lower portion; or if the bulb is ever so slightly compressed by the force of the steam, the indications in each instance would be incorrect.

The changing pressure in locomotive boilers from their small steam space and rapid consumption renders slight variations of temperature easily effected by atmospheric influence, or other disturbing causes. If the tube were of greater length and surrounded by an atmosphere of the same temperature as is in the boiler, thermometric gauges might be depended upon, but for ordinary locomotive purposes there are several impediments to their successful application.

Besides mercurial gauges, spring gauges have been made of the form shown in Fig. No. 44, which is a small cylinder exactly one square inch area, whose piston P is made to com-

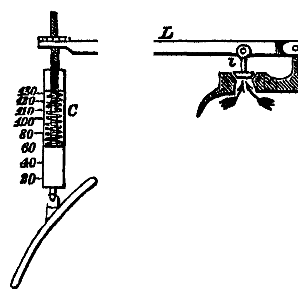
Fig. 44.



press the spiral spring S S, according to the force of the steam on the piston, and an index attached to the piston rod shows the force on a scale *F* adjusted to the spring. This is, in fact, Watt's indicator applied as a permanent gauge.

Salter's well-known spring balance, Fig. No. 45, also measures the pressure by the upward force of the steam on the safety valve *l*, compressing a double spiral spring within the cylindrical case C, by the action of the lever L, and showing the force on a scale of pounds.

Fig. 45.



CHAPTER II.

MECHANICAL FORCE OF STEAM.

This force is dependent upon the pressure under which steam is generated, for it varies in the ratio of that pressure. Under the atmospheric pressure of 15 lbs. per square inch, water boils at a temperature of 212°, and the steam evolved has a force of 15lbs. per square inch; but when the atmospheric pressure is wholly withdrawn by an air pump, water boils at a temperature as low as 70° and produces steam, having a force of about ⅓ of a lb. or · ·72 inches of mercury.

As 70° is a temperature considerably below that of the human body (98°), the heat of the hand would produce ebullition in a vacuum. For instance, if water were boiled in a glass phial, and corked whilst it still contained steam, it would on being withdrawn from the heat cease to boil; but if immersed in cold water boiling would recommence, because the cold had condensed the steam and removed the pressure from the water, but if again immersed in hot water steam would be formed, and the boiling cease from the increased pressure on the water. It is found by experiment that for every variation of one inch of mercury or one half pound on the pressure on the water the boiling point varies 1·76° as under:—

Barometer in Mer.	Boiling Point. Fahr.
27	206·9
27½	207·8
28	208·7
28½	209·5
29	210·4
29½	211·2
30	212·0
30½	212·8
31	213·6

For each 2·6 per cent. of common salt in water the boiling point rises 1°, and when it reaches 36 per cent. the water is said to be saturated with salt, and the boiling point raised to 226° or 228°.

Sea water contains about 3½ per cent. of saline matter, which has called forth ingenious processes of distilling salt water for marine boilers, or of brine pumps for removing these saline matters deposited by boiling, and which unless removed speedily obstruct the generation of steam. With 3 per cent. of saline matter water boils at 213·2° temperature and with 6 per cent. at 214·4°.

Steam is produced at all temperatures; even in freezing, natural evaporation may be seen, as if the river, streamlet or lake were smoking; and it possesses mechanical force even at such low temperatures, as is shown in the following table by Dalton:—

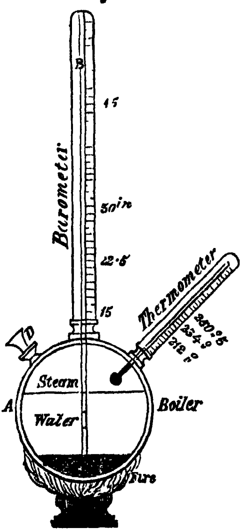
Table No. 35.

ELASTIC FORCE OF STEAM FROM 32° TO 212° IN INCHES OF MERCURY.

Temp. Deg.	Force. In. mer.	Temp Deg.	Force. In. mer.	Temp. Deg.	Force. In. mer	Temp. Deg	Force. In. mer	Temp. Fah.	Force. In. mer.
32	0·200	69	0·698	105	2·18	141	5·90	177	14·22
33	0·207	70	0·721	106	2·25	142	6·05	178	14·52
34	0·214	71	0·745	107	2·32	143	6·21	179	14·83
35	0·221	72	0·770	108	2·39	144	6·37	180	15·15
36	0·229	73	0·796	109	2·46	145	6·53	181	15·50
37	0·237	74	0·823	110	2·53	146	6·70	182	15·86
38	0·245	75	0·851	111	2 60	147	6 87	183	16·23
39	0·254	76	0·880	112	2·68	148	7·05	184	16·61
40	0 263	77	0·910	113	2·76	149	7·23	185	17·00
41	0·273	78	0·940	114	2 84	150	7·42	186	17·40
42	0·283	79	0·971	115	2·92	151	7·61	187	17·80
43	0·294	80	1·00	116	3·00	152	7·81	188	18·20
44	0·305	81	1·04	117	3·08	153	8·01	189	18·60
45	0·316	82	1·07	118	3·16	154	8·20	190	19·00
46	0·328	83	1·10	119	3·25	155	8·40	191	19·42
47	0·339	84	1 14	120	3·33	156	8·60	192	19·86
48	0·351	85	1·17	121	3·42	157	8·81	193	20·32
49	0·363	86	1·21	122	3·50	158	9·02	194	20·77
50	0·375	87	1·24	123	3·59	159	9·24	195	21·22
51	0·388	88	1·28	124	3·69	160	9·46	196	21·68
52	0·401	89	1·32	125	3·79	161	9·68	197	22·13
53	0·415	90	1·36	126	3·89	162	9·91	198	22·69
54	0·429	91	1·40	127	4·00	163	10·15	199	23·16
55	0·443	92	1·44	128	4·11	164	10·41	200	23·64
56	0·458	93	1·48	129	4·22	165	10·68	201	24·12
57	0 474	94	1·53	130	4·34	166	10·96	202	24·61
58	0·490	95	1·58	131	4·47	167	11·25	203	25·10
59	0·507	96	1·63	132	4·60	168	11·54	204	25·61
60	0·524	97	1·68	133	4·73	169	11·83	205	26·13
61	0·542	98	1·74	134	4·86	170	12·13	206	26·66
62	0·560	99	1·80	135	5·00	171	12·43	207	27·20
63	0·578	100	1·86	136	5·14	172	12·73	208	27·74
64	0·597	101	1·92	137	5·29	173	13·02	209	28·29
65	0·616	102	1·98	138	5·44	174	13·32	210	28·84
66	0·635	103	2·04	139	5·59	175	13·62	211	29·41
67	0·655	104	2·11	140	5·74	176	13·92	212	30·00
68	0·676								

To produce steam of a pressure greater than the atmosphere, requires the water to be boiled in a close vessel until it has attained the force necessary to perform its mechanical duty.

Fig. 46.



The gradual accumulation of that force in a steam boiler, and the ratio of the temperature to that force are illustrated in Fig. No. 46, which represents a spherical boiler partly filled with mercury and partly filled with water. B, a barometric glass tube open at both ends, reaching nearly to the bottom of the mercury. C, a thermometer with its end reaching nearly to the surface of the water. D, the supply cock for filling the boiler. On heat being applied below the boiler whilst the supply cock D is open, the steam will pass out as formed at a temperature of 212°, and the mercury remain stationary by the pressure of the atmosphere on it in the tube B being equal to the pressure of the steam on the water in the boiler A. If D be then shut this equality of pressure ceases, and the mercury begins gradually to ascend the tube in the ratio of the accumulating force of the steam above the force of the atmosphere. The thermometer also rises by the increased temperature of the steam. Now, if the pressure of the steam has raised the mercury 15 inches in the tube B, indicating a force of 7½ lbs. above that of the atmosphere, the thermometer will have risen to 234°, being the heat of that pressure. At 250½° the mercury in the tube will have risen 30 inches, showing a pressure of 15 lbs. above the atmosphere with a temperature of 250·5°, or an actual pressure of 30 lbs. per square inch on the water. If the cock D be now opened the steam will rush out, and the thermometer rapidly fall to 212°, and the mercury in the tube B to zero again. The elastic or mechanical force of steam increases in a greater ratio than its temperature, for at 212° its force is 15 lbs., at 250½° it is 30 lbs., and at 285° it is 52½ lbs. The first 38½° increases the force 15 lbs., but by 34½° more heat its force is increased 22½ lbs.

The following table shows this ratio of increase at various temperatures:

TABLE No. 36.

Temp. Deg. Fah.	FORCE OF STEAM IN				
	Atmospheres.	Open tube. In. mer.	Bar. tube. In mer.	Above atm lbs. avoir.	Full force. lbs. avoir.
212	1	0	30	0	15
230·96	1½	15	45	7 5	22·5
253·52	2	30	60	15·	30·
293·72	4	90	120	45	60
341·96	8	210	240	105	120
398·48	16	450	480	225	240
433·56	22	690	720	360	375

From this it is seen, that while the temperature is little more than doubled, the force is increased from 15 to 345 lbs. or 23 times. If it were not for this increasing force in proportion to the additional heat introduced, high-pressure steam engines would, for all ordinary pressures, be unable to enter into an economical competition with condensing engines. For instance, the working pressure of 4 lbs. steam has been shown to be 16 lbs. Its relative volume to water is 1411, but the relative volume of high-pressure steam of 31 lbs. or 16 lbs. working pressure is only 857, or less than five-eighths of the volume or cylinders-full of the low-pressure steam.

The mechanical force of steam above atmospheric pressure is thus given by Taylor:

Table No. 37.

FORCE OF STEAM FROM 212° TO 320° IN INCHES OF MERCURY.

Temp. Deg.	Force. In. mer.	Temp. Deg.	Force. In. mer.	Temp. Deg.	Force. In. mer.	Temp. Deg.	Force. In. mer.	Temp. Deg.	Force. In. mer.
212	30·00	234	44·60	256	65·50	278	94·70	300	135·75
213	..	235	45·50	257	66·60	279	96 26	301	135·60
214	31·00	236	46·40	258	67·75	280	97·75	302	137·55
215	..	237	47·30	259	69·00	281	99·25	303	139·75
216	32·30	238	48·20	260	70·12	282	100·70	304	141·90
217	33·00	239	49·10	261	71·25	283	102·20	305	144·05
218	33·70	240	50·00	262	72·45	284	103·80	306	146·15
219	34·20	241	50·90	263	73·52	285	105·60	307	148·30
220	35·00	242	51·75	264	74·80	286	107·30	308	150·65
221	35·50	243	52·62	265	76·00	287	109·00	309	157·70
222	36·20	244	53·50	266	77·25	288	110·80	310	155·00
223	37·00	245	54·40	267	78·50	289	112·65	311	157·20
224	37·50	246	55·30	268	79·80	290	114 50	312	159·45
225	38·00	247	56·25	269	81·14	291	116·40	313	161·75
226	38·80	248	57·20	270	82·50	292	118·30	314	164·20
227	39·50	249	58·20	271	83·90	293	120·25	315	166·70
228	40·20	250	59·12	272	85·45	294	122·20	316	169·15
229	40·85	251	60·10	273	86·95	295	124·15	317	171·70
230	41·55	252	61·12	274	88 50	296	126·05	318	174·30
231	42 25	253	62·15	275	90·00	297	128·00	319	176·80
232	43·00	254	63·20	276	91·55	298	129·80	320	179·40
233	43·75	255	64·40	277	93·15	299	131·62		

Condensation of Steam.

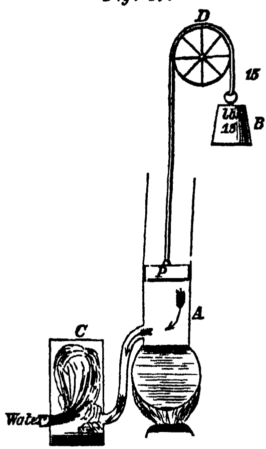
This is an important source of economy in a low-pressure engine, and was first economically applied by Watt employing a separate cylinder for condensation; but before his time it had been condensed in the working cylinder, causing a great loss of heat each stroke of the engine.

By Watt's plan, the steam now passes from the working cylinder into another one called the condenser, into which water is introduced to condense the steam. In Fig. No. 46, (see p. 163,) if, instead of opening the cock D, water had been introduced by that pipe to the boiler A, the steam would have been condensed, and the temperature and pressure reduced accordingly. The quantity of water required for condensation is considerable. If the total heat of steam of 15 lbs. pressure is nearly 1178°, the water required for condensation would be indicated by the amount of heat to be abstracted from the steam and absorbed by the water. If we take the heat of water as 52°, and of steam as 1178°, their difference is 1126°, to be divided by the quantity of heat which can be absorbed by the water without impairing the vacuum in the condenser. If this be taken as 40°, we have $\frac{1126}{40} = 28$ times, but if it be taken as 60°, which can be so absorbed, we have $\frac{1126}{60} = 18{\cdot}7$ times, or 28 times, as the respective quantities of water required for condensation, or from 18 to 28 times the quantity necessary to form the steam, but variable according to the temperature of the condenser and condensing water. Since locomotive engines require tanks holding from 1400 to 1700 gallons of water for steam only, it will be seen that to carry about 20 times that quantity, or from 120 to 150 tons additional, would be a load of itself, besides the more complicated machinery of a condensing engine. Whilst water remains the agent of condensation, these are palpable difficulties in applying this plan to locomotives, although some ingenious attempts have been made by Mr. Adams to do so on an engine at the Eastern Counties Railway.

The economy of condensing engines arises from their using low-pressure steam, which has a large volume, and the additional pressure derived from the vacuum in the condenser. For if this vacuum is equal to 12 lbs., it adds that amount to the pressure in the boiler above the atmosphere, less the friction of the condensing machinery.

This pressure of 12 lbs. is that portion of the atmospheric pressure which is unbalanced by the pressure in the condenser,

Fig. 47.



and may be illustrated by diagram No. 47, where A is a glass tube having a bulb at one end containing water, and fitted with the piston P. On heat being applied steam will be produced and the piston forced up to the top of the tube, and if the tube be then immersed in cold water the steam will be condensed, and the pressure of the air force the piston down again.

This, however, would also cool the cylinder, requiring as much heat to raise it again to the steam temperature, a double source of expence, but when conveyed to the separate cylinder C this loss is avoided. The downward pressure of the air would then be indicated exactly by a weight B suspended from the piston P over the pulley D, and over a perfect vacuum this would be $14\frac{3}{4}$, or say 15 lbs. per square inch in whole numbers.

Volume, Force, and Condensation of Steam.

If the cylinder A, Fig. No. 47, were 1 square inch area by 1700 inches high, it would contain 1 cubic inch of water converted into steam of atmospheric pressure, and this steam would raise 15 lbs. to that height (nearly 142 feet). It is found that the volume of steam at that pressure is very nearly 1700 times that of the water which produced it, hence the weight which the steam would raise being multiplied by the height, gives the effect produced by 1 cubic inch of water as steam = 142 ft. × 15 lbs. = 2130lbs. raised 1 foot high. By condensing the steam into water again the atmosphere would force the piston down through an equal distance with an equal effect; or if the cylinder was made air-tight at top, and steam of atmospheric pressure introduced, a like result would take place.

If the pressure of steam is raised to 30 lbs. per inch, its volume is diminished *to only 883 times* that of the water which produced it, or equal to a height of $73\frac{1}{2}$ ft. × 30 lbs. pressure = 2205 lbs. as its mechanical force. At 100 lbs. per inch the volume of steam to water is as 295 to 1, or 24·58 ft. and 24·58 × 100 = 2458 lbs. raised 1 foot. This shows that the effect increases slowly with the pressure; but it is usual to take the mechanical value of 1 cubic inch of water as equal to raise 1 ton 1 foot high, and the complete condensation of 1 cubic inch of water as of an equivalent value.

This gradual diminution of bulk from increased pressure is nearly as given in TABLE No. 38.

Taking the steam produced under a pressure of 15 lbs. per square inch as one volume, or unity, the ratio of bulk to other pressures is approximately

Lbs.		Volume.		Spaces
15	=	1	or say	50
30	about	·5	or	$\frac{25}{50}$
45	„	·36	„	$\frac{18}{50}$
60	„	·28	„	$\frac{14}{50}$
75	„	·22	„	$\frac{11}{50}$
90	„	·18	„	$\frac{9}{50}$
150	„	·16	„	$\frac{8}{50}$
120	„	·14	„	$\frac{7}{50}$

BY EXPERIMENT.			
Lbs.	Volume.	Lbs.	Volume.
5	4617	75	383
6	3897	80	362
7	3376	90	325
10	2426	100	295
12	2050	110	271
15	1669	120	251
16	1573	130	233
18	1411	140	218
20	1281	150	205
30	883	160	193
40	679	170	183
45	610	180	174
50	554	190	66
60	470	200	158
70	408		

Since each succeeding addition of pressure diminishes the volume of steam, causing it to act through a shorter and shorter distance, although with greater force through that distance, it follows that increased pressure requires an increased supply of both heat and water to produce a volume of steam corresponding to low-pressure steam. The power would be increased in the ratio of the pressure and diameter of the cylinder; but if no increase of power is required, a smaller cylinder or greater expansive action would be necessary to economy.

The frictional surface of a small piston is, however, greater for its area of acting surface than a large one, whilst an increase of pressure gives corresponding advantages to the larger piston, as seen in the following table:

TABLE, No. 39.

COMPARATIVE RUBBING AND PRESSING SURFACES OF PISTONS, WITH INCREASING POWER FOR EACH ADDITIONAL 10 LBS. PER SQUARE INCH.

Diam.	PISTON.			Power for each 10 lbs. press. on the piston.
	Rubbing surface, or circumference.	Acting surface, or area.	Ratio of acting to rubbing.	
Inch.	Lineal inch.	Square inch.	Rub. = 1.	lbs.
6	18·849	28·274	1½	282·7
7	21·991	38·481	1¾	384·8
8	25·132	50·265	2	502·6
9	28·274	63·617	2¼	636·1
10	31·416	78·54	2½	785·4
11	34·557	95·03	2¾	950·3
12	37·699	113·097	3	1130·9
13	40·84	132·732	3¼	1327·3
14	43·98	153·938	3½	1539·3
15	47·124	176·715	3¾	1767·1
16	50·265	201·062	4	2010·6
17	53·407	226·98	4¼	2269·8
18	56·548	254·469	4½	2544·6
19	59·69	283·529	4¾	3835·2
20	62·832	314 16	5	3141·6
21	65·793	346·36	5¼	3463·6
22	69·115	380·13	5½	3801·3
23	72·256	415·476	5¾	4154·7
24	75·398	452·39	6	4523·9

By this table it is seen that whilst a 9-inch piston has an area of only $2\frac{1}{4}$ times its boundary or rubbing surface, an 18-inch piston has an area of double that ratio, or $4\frac{1}{2}$ times its circumference. The depth of the respective pistons may slightly but not materially alter this ratio, whilst the increase of power for an additional 10 lbs. of pressure on each square inch is for the 9-inch piston 636 lbs., and for the 18-inch piston 2544 lbs., or four times that of the smaller piston.

Volume of Steam.

In determining the size of cylinder for any given pressure, or for any given boiler, the volume of steam is a necessary element in the calculation, and for this purpose the following rules are submitted for ordinary steam. They are based on the ascertained facts that steam of atmospheric pressure is very nearly 1700 times the volume of the water which produced it; and that for each additional degree of heat of Fahrenheit's scale, steam expands when in contact with water, ·00202 times its bulk, hence for any other pressure we have:

$$\text{Volume} = \frac{1700 \times 14{\cdot}75}{\text{pressure}} \times \frac{1 \times {\cdot}00202\ (\text{temp.}-32)}{1 \times {\cdot}00202 \times 180}$$

The following rules are very simple in their application:

By Pambour,

$$\text{Volume} = \frac{10000}{1{\cdot}421 \times {\cdot}331\ \text{pressure}}$$

Pole gives,

$$\text{Volume} = \frac{24250}{\text{pressure}} + 65$$

Ex.—Required the volume of steam of 100 lbs. pressure per square inch relatively to water as 1?

By Pambour,

$$\frac{10000}{100 \times {\cdot}331 \times 1{\cdot}421} = 289{\cdot}6 \text{ times.}$$

By Pole,

$$\frac{24250}{100} + 65 = 307{\cdot}5$$

or a difference of nearly 18 volumes of the water forming the steam.

The volume may also be found by adding 4·29 to the pressure in pounds per square inch, and deducting the logarithm of this sum from 4·4799. The natural number of the remainder will give the ratio of the volume of steam to water.

For the last example we have—

log. of 100 + 4·29 = 2·0182; and 4·4799
less 2·0182 = 2·4617

and the natural number of 2·4617 = 289·4

or nearly the same as Pambour's formula gives.

Tate's formula is, volume = 12·5 + 20570 pressure—·9301, which gives very near results to experiment, but it is of a more complex description than those previously given.

The volume of steam under expansion may be found by adding 459, to the respective temperature, before and after expansion, and dividing the greater by the lesser sum. The volume due to the lowest temperature multiplied by the quotient will give the volume for the highest temperature.

Frost's experiments on heating steam separated from water show a very different ratio of expansion. At the temperature of 216° the volume was doubled, at 228° it was trebled, and at 650° it was more than seven times the volume at 212°, or upwards of eight volumes altogether. Whether the manner of conducting these experiments had anything to do with the results or not, they sufficiently indicate that further investigation is necessary to determine the volumes of steam from direct experiment, and not as generally by comparison with permanent gases, more particularly at high temperatures.

Velocity of Steam.

Steam is estimated to flow into a vacuum with a velocity equal to that due to a body of the same density falling through a space equal to the height of a column of steam of the given pressure. For instance, it would require a column of steam about 63500 feet high to give a pressure of 45 lbs. upon a square inch. The velocity due to the pressure may be found by adding 4·29 to the pressure in pounds per square inch, and deducting the logarithm of this sum from the logarithm of the pressure. To one-half the remainder add 3·3254, and the natural number of this sum will be the velocity in feet per second.

Example. Required the velocity with which steam of 100 lbs. pressure would rush into a vacuum?

Pressure 100 lbs. whose log. = 2·00000
and pressure 100 + 4·29 = 104·29 whose log. = 2·01828

and remainder ÷ ½) $\bar{9}$·98172

leaves $\bar{9}$·99086
to which add 3·3254

gives 3·31626 whose natural number = 2071 feet per second.

TABLE, No. 40.

VELOCITY OF STEAM IN FEET PER SECOND, BY THIS RULE.

Pressure.	Velocity in feet.	Pressure.	Velocity in feet.	Pressure.	Velocity in feet
lbs.	per second.	lbs.	per second.	lbs.	per second.
5	1552	80	2061	155	2085·3
10	1770	85	2064	160	2086
15	1856	90	2067	165	2086·7
20	1919	95	2069	170	2087·5
25	1955	100	2071	175	2088·3
30	1978	105	2073	180	2089
35	1997	110	2075	185	2089·7
40	2010	115	2077	190	2090·5
45	2021	120	2079	195	2091·3
50	2030	125	2080	200	2092
55	2037	130	2081	205	2092·7
60	2043	135	2082	210	2093·5
65	2049	140	2083	215	2094·3
70	2053	145	2083·7	220	2095
75	2057	150	2084·5	250	2132

The difference between the velocities of any two pressures is the velocity with which steam would flow into steam of a lower pressure. Thus, steam of 120 lbs. gross pressure, would flow into steam of 20 lbs. pressure, at a velocity of 2079 – 2010 = 69 feet per second.

Such is the estimated velocity of steam when there are no frictional obstructions to its passage; but, as these are conditions not obtainable in practice, the velocity will be reduced in proportion to the resistances it has to overcome. In locomotive engines at high velocities these resistances are very considerable; for, with a back pressure from $\frac{1}{16}$ to $\frac{1}{4}$ of that in the boiler, narrow steam-ports, incomplete exhaustion, and rapid action of the slide, this velocity it is evident must be very materially lessened. Those who have carefully observed indicator cards will have seen that the steam in the cylinder, only attains a force near that in the boiler, when the resistances against the piston retard its progress until such force has accumulated; but, if the resistance does not require that force, the piston moves on more rapidly than allows time for such accumulation.

The steam may, therefore, be 100 lbs. in the boiler; but, if 35 lbs. will overcome the resistances againt the piston, including the back pressure, the piston will move on with a velocity to prevent a greater pressure. Yet if that piston were arrested, even for a second, the pressure would equalize itself very nearly in the boiler and in the cylinder. This indicates that the velocity of the steam, in passing from the boiler to the cylinder, is not so great but that the motion of the piston sensibly affects its accumulation there. Since 1000 feet per minute is an extreme velocity for a piston, it leads to the conclusion that the actual velocity of steam, in a locomotive engine, is moderate; but what the exact velocity may be remains to be determined by experiments.

Temperature and Force of Steam.

To determine the relation between the force and temperature of steam a great many experiments have been made, both in Europe and America. In 1762, Watt commenced the modern investigations of the properties of steam, and his splendid practical success gave an impetus to such inquiries, which has not been exhausted. In 1829, the French Academy of Science appointed a Committee to solve the question by experimental research on a most elaborate scale. These experiments were conducted by Messrs. Arago and Dulong, aided by the best instruments, and their own extensive knowledge of natural philosophy. Having decided, on testing, the force of steam by a barometric tube filled with mercury, they had one made in 13 pieces, each 78¾ inches long, to join together so as to form one enormous glass tube, having a bore of about ⅕ of an inch diameter for the mercurial column. This was erected against the old church tower of Genevieve, and experiments made to determine the accuracy of Mariotte's law of air, that its pressure or force is inversely as the space a given quantity is made to occupy. Having found this law very nearly correct to the high pressure of 24 atmospheres, and as the fears of the authorities for the old Tower from an explosion of the boiler led the large barometer to be taken down, they employed carefully constructed air-gauges similar to figs. Nos. 41, 42, to determine the force of the steam. One thermometer was placed in the boiler to ascertain the temperature of the steam, as in fig. No. 46, and another placed nearly to the bottom of the water, that the temperature of both water and steam might be ascertained at once, which were found to correspond exactly, and the steam to be of the same temperature as the water which produced and was in contact with it.

The compression of the air in the gauge, by the force of the steam acting on the mercury, gave its pressure at the same time; so that the force and temperature were simultaneously determined at the same instant up to 24 atmospheres, and by calculation extended to 50 atmospheres, as given in the following table.

Table, No. 41.

MESSRS. ARAGO AND DULONG'S EXPERIMENTS OF THE TEMPERATURE AND PRESSURE OF STEAM.

Atmospheres	Deg. Fah.	Deg. Cent.	lbs. per Inch.	Kil. per sq Centi
1	212	100	14·706	1·0335
1½	233·96	112·2	22·059	1·5502
2	250·52	121·4	29·412	2 067
2½	263·84	128·8	36·765	2·5837
3	275·18	135·1	44·118	3·1005
3½	285·08	140·6	51·471	3·6172
4	293 72	145·4	58·824	4·134
4½	300·30	149·6	66·177	4·6507
5	307·54	153·1	73·53	5·1675
5½	314·24	156·8	80·883	5·7842
6	320·36	160·2	88·236	6·2010
6½	326·26	163·48	95·589	6·7177
7	331·70	166 5	102·942	7·2345
7½	336·86	169·37	110·295	7 7512
8	341·78	172·1	117·648	8·268
9	350·78	177·1	132·354	9·3015
10	358·88	181 6	147·060	10·3350
11	366·85	186·0	161·766	11·3685
12	374·00	190 0	176·472	12·402
13	380·66	193·7	191·178	13·435
14	386 94	197·19	205·884	14·469
15	392·86	200·48	220 59	15·5025
16	398·48	203·6	235·296	16·536
17	403·82	206·5	250·002	17·5695
18	408·92	209·4	264·708	18·6030
19	413·78	212·2	279·414	19·6365
20	418·46	214·7	294·120	20·67
21	422·96	217·2	308·826	21·7035
22	427·28	219·6	323·532	22·7370
23	431·42	221·9	338·238	23·7705
24	435·56	224·2	352·944	24·8040
25	439·34	226·3	367·650	25·8375
30	457·16	236·2	441·18	31·005
35	472·73	244·85	514·71	36·1725
40	486·59	252·55	588·24	41·34
45	499·13	259·52	661·77	46·5075
50	510·60	265·89	735·33	51·6750

After mathematically analysing the results of these experiments, and the law by which they were extended to 50 atmospheres, and reviewing the previous laws of Tredgold and others, Pambour gives the following useful table as a close approximation to the real values of steam.

Table, No. 42.

PRESSURE, TEMPERATURE, AND RELATIVE VOLUME OF STEAM TO THE WATER THAT PRODUCED IT, TAKING THE WATER AS UNITY OR 1.

Pressure per square inch.	Temp.	Volume of water being 1.	Pressure per square inch.	Temp.	Volume of water being 1.	Pressure per square inch.	Temp.	Volume of water being 1.
lbs.	Fah	No	lbs	Fah.	No.	lbs.	Fah.	No.
1	102·9	20954	38	265·3	710	75	308·9	381
2	126·1	10907	39	266·9	693	76	309·9	377
3	141·0	7455	40	268·4	677	77	310 8	372
4	152·3	5695	41	269·9	662	78	311·7	368
5	161·4	4624	42	271·4	647	79	312·6	364
6	169·2	3901	43	272·9	634	80	313·5	359
7	176·0	3310	44	274·3	620	81	314·3	355
8	182·0	2985	45	275·7	608	82	315·2	351
9	187·4	2676	46	277·1	596	83	316·1	348
10	192·4	2427	47	278·4	584	84	316·9	344
11	197 0	2222	48	279·7	573	85	317·8	340
12	201·3	2050	49	281·0	562	86	318·6	337
13	205·3	1903	50	282·3	552	87	319·4	333
14	209·0	1777	51	283·6	542	88	320·3	330
15	213·0	1669	52	284·8	532	89	321·1	326
16	216·4	1572	53	286·0	523	90	321·9	323
17	219·6	1487	54	287·2	514	91	322·7	320
18	222·6	1410	55	288·4	506	92	323·5	317
19	225·6	1342	56	289·6	498	93	324·3	313
20	228·3	1280	57	290·7	490	94	325·0	310
21	231·0	1224	58	291·9	482	95	325·8	307
22	233·6	1172	59	293·0	474	96	326·6	305
23	236·1	1125	60	294·1	467	97	327·3	302
24	238·4	1082	61	294 9	460	98	328·1	299
25	240·7	1042	62	295·9	453	99	328·8	296
26	243·0	1005	63	297·0	447	100	329·6	293
27	245·1	971	64	298·1	440	105	333·2	281
28	247·2	939	65	299·1	434	120	343·3	249
29	249·2	909	66	300·1	428	135	352·4	224
30	251·2	882	67	301·2	422	150	360·8	203
31	253·1	855	68	302·2	417	165	368·5	187
32	255·0	831	69	303·2	411	180	375·6	173
33	256·8	808	70	304·2	406	195	382·3	161
34	258·6	786	71	305·1	401	210	388·6	150
35	260·3	765	72	306·1	396	225	394.6	141
36	262·0	746	73	307·1	391	240	400·2	133
37	263·7	727	74	308 0	386			

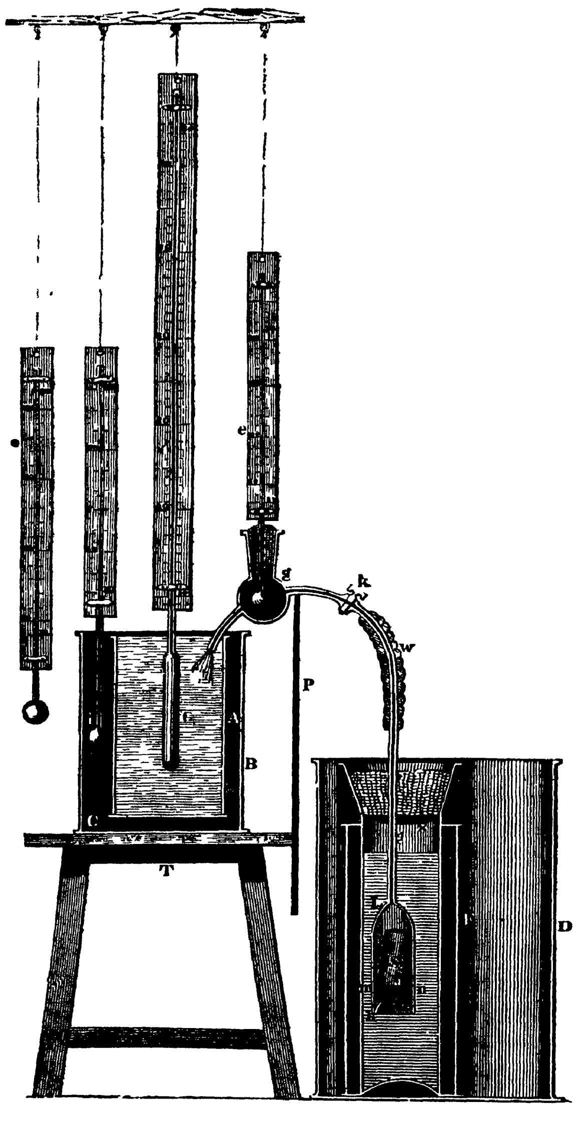
In 1832-3 The Franklin Institute of America made a series of elaborate experiments to determine the diffused heat in steam of 212° to 215°, by condensing a given weight of steam in a given quantity of water.

Fig. No. 48, shows the method adopted and care exercised to obtain accurate results. F, the boiler into which the copper vessel L, containing the heater S, was placed to sustain the temperature of the boiler during the trial. W, *k*, *g*, a pipe for conveying the steam to the condenser A, filled with a known quantity of water. The steam was allowed to flow from the boiler and condense until the condenser was filled, when it was shut off by the cock *k*. The condenser and contents being then accurately weighed showed the weight of steam which had been condensed, and the thermometer *t* showed the increase of the temperature of the water in A. Of the three other thermometers, *e* showed the temperature of the steam, *i* the temperature within the radiation protector B, and o the surrounding temperature of the apartment.

These thermometers were all carefully adjusted and corrections made for their respective duties, and both condenser and boiler incased to prevent loss of heat by radiation. A reflecting tin plate, P, was also placed between them, to guard against the least influence from the boiler affecting the condenser.

The principal results are given in table No. 43.

Fig. No. 48.



Table, No. 43.

LATENT OR DIFFUSED HEAT IN STEAM.

STEAM.			WATER.				DIFFUSED HEAT.	
Temp. before condensation.	Temp. lost by condensation.	Quantity condensed.	Condenser, made of.	Quantity in condenser.	Temp. before the admission of steam.	Temp. increased by the condensation of the steam admitted.	In each experiment.	Mean of experiments.
Fah.	Fah.	Grains	Material.	Grains	Fah.	Fah.	Fah.	Fah.
214	127·5	347	thin copper.	38659	75·35	10·75	1086·5	
215	129·25	504	,,	38659	70·9	14·85	1025·5	
215	139·25	241	,,	39305	68·75	7	1018·95	
214	136·75	250	,,	39305	7[illegible]	7·25	1019·55	
								1037·87
213	120·35	299	thick glass.	17112	74·6	18·05	996·9	
215	127	192	,,	17112	75·5	12·5	1077·82	
214	139·5	156	,,	17428	64·6	9·9	1044·8	
213	139·75	127	,,	17428	65·25	8	1035·75	
								1038·51
213	134·2	167	thin glass.	18405	68·5	10	987·3	
212	143·5	156	,,	17428	58·5	10	1003·3	
								995·3
213	123·8	169	thick sheet iron.	13152	75·1	14·1	1027·2	
214	124·2	190	,,	13152	73·7	16·1	1043·5	
								1035·35

Having made these experiments on diffused heat the Committee extended their researches to ascertain the relation between the temperature of the steam and its elastic force. For this purpose they employed a small boiler 12 inches diameter and 34¼ inches long, having a glass window in each end for observation, besides the usual gauge-cock and glass water-gauge. A mercurial cistern was attached to the boiler, and into the cistern was fitted, steam tight, an air-gauge 26·43 inches long, of the class fig. No. 41, having its open end in the mercury. A scale of pressures having been carefully adjusted to this gauge-tube, thermometers were applied to test the temperature of the water and of the steam in the boiler. Much care was taken to obtain accurate results from the pressure of the steam on the gauge, and to note at the same time the temperature indicated by the thermometers.

As with all other experiments on steam and water in contact with each other, the temperature was ascertained to be the same in both.

When the first trials were completed it was found that they differed considerably from those of the French Academy, when they were repeated with all the advantage of experience and precaution gained from the first series. The results of both series are given in Tables, Nos. 44, 45, and Table No. 46, is a summary of the mean pressures in atmospheres.

Table, No. 44.

ELASTIC FORCE OF STEAM BY THE FRANKLIN INSTITUTE.

(First Series of Experiments.)

Temp of steam	Temp of air in steam gauge.	Volumes of air at 48°	Height of mercury in steam-gauge.	Compressure on air in steam gauge equal to	Total elasticity per square inch, in	
Fahr.	Fahr.	Vols.	In. mer	In mer.	In mer.	Atmos. of 30 in. mer
262¼	74	3 737	15·04	59·09	72·99	2·43
268½	,,	3·259	16·34	67·76	82·97	2·76
275½	,,	2·898	17·34	76·20	92·42	3 08
286½	,,	2·319	18·94	95·23	113·07	3·77
296½	,,	1·948	19·94	113·36	132·21	4·41
298½	,,	1·891	20·11	116·76	135·80	4·53[2]
302	,,	1·767	20·44	124·98	144·33	4·81[3]
305½	75	1·641	20·79	134·57	154·28	5·14
513¼	,,	1·422	21·39	155 30	175·61	5 85[4]
317¾	,,	1·332	21·64	165·79	186·36	6·21
320¾	76	1 255	21·79	173·20	193·92	6·46
327¾	,,	1·113	22·24	198·41	219·14	7·30
333¾	,,	0·950	22·69	232·46	254·09	8·47

Table, No. 45.

ELASTIC FORCE OF STEAM BY THE FRANKLIN INSTITUTE.

(Second Series of Experiments.)

Temp. of steam.	Temp. of air in steam-gauge.	Volumes of air at 48°	Height of mercury in steam-guage.	Compressure on air in steam-gauge equal to	Total elasticity per square inch, in	
Fahr.	Fahr.	Vols.	In. mer.	In. mer.	In. mer.	Atmos. of 30 in. mer
248¼	53	4·277	14·04	16·19	59·08	1·97
269½	52	3·026	17·34	65·29	81·51	2·72
284½	,,	2·152	19·64	91·76	110·30	3·68
289½	,,	1·974	20·06	100 05*	119·02	3·97
294½	53	1·802	20·56	109·63	129·11	4·30
299½	54	1·611	21·04	122·66	142·62	4·75
304½	54½	1·500	21·34	131·66	151·92	5·06
310¼	,,	1·382	21·64	142·94	163·51	5·45
314¾	55	1·233	22·04	160·26	181·23	6·04
319¾	55½	1·124	22·34	175·86	197·13	6·57
329¾	56	0·937	22·84	210·84	232·62	7·75
334½	57	0·904	22·94	218·60	240·48	8·02
338¾	57½	0·870	23·04	226·92	548·92	8·30
345	,,	0·805	23·24	245·44	267·62	8·92
348	58	0·771	23·34	256·05	278·33	9·28
350	,,	0·737	23·44	267·97	290·35	9·68
352	,,	0·719	23·50	274·92	297·36	9·91
346	62	0·785	23·28	251·78	274·00	9·13

Table, No. 46.

MEAN ELASTIC FORCE OF STEAM, FROM THE FRANKLIN EXPERIMENTS IN ATMOSPHERES.

Pressure	Observed Temp	Pressure	Observed Temp	Pressure	Observed Temp	Pressure	Observed Temp
Atmos	Fahr.	Atmos	Fahr.	Atmos.	Fahr	Atmos.	Fahr.
1	212	3½	284	6	315½	8½	340½
1½	235	4	291½	6½	321	9	345
2	250	4½	298½	7	326	9½	349
2½	264	5	304½	7½	331	10	352½
3	275	5½	310	8	336		

M. Regnault has recently concluded an elaborate series of experiments on the heat and force of steam for the French Government. The practical results of these valuable experiments are given in tables Nos. 47—49. From these tables it appears that there is a regular increase in the total heat of steam up to the extent of these trials, or to 13·6 atmospheres. accompanied by a gradual decrease of diffused heat. It had hitherto been held that the heat of steam was the same for all pressures, but Mr. Regnault shows an increase of 45° from a pressure of 15 lbs. to one of 200 lbs. This is, however, so small an increase that it could scarcely develope itself at the low pressures experimented on by Watt and Southern, who differed as to whether it was the sensible or diffused heat of steam which was constant. Watt's view was that the diffused heat was not constant, but could be found by deducting the thermometric heat from the total heat of steam. Southern held that the diffused heat was constant, and this heat added to the thermometric heat gave the total heat. Regnault's experiments show that neither are constant, but that the diffused heat decreases from 973° to 880° or 93°, and that the thermometric heat increases from 1186° to 1231° or 45°. The difference between Regnault and Watt is therefore 45°, and between Regnault and Southern 93°, over a range of pressure many times greater than was experimented on by these early and able pioneers of steam engineering.

TABLE, No. 47.

EXPERIMENTS UNDER VERY LOW PRESSURES.

Experiments.	Pressure Milemetre.	Temperature.	Quantity by weight after condensation.	Quantity in calometer.	Temperature.	Temperature increased by condensation.	Total heat.	Absorbed by the steam.
No.	Mm	Cent.	Grms.	Grms.	Cent.	Cent.	Units.	Units.
1	4·5	– 0·2	5·250	542·0	9·21	5·748	601·5	592·3
2	3·9	– 2·1	5·180	541·8	12·17	5·713	608·9	596·7
3	4·6	0·	5·127	541·8	12·44	5·624	605·8	593·4
4	7·7	+ 7·4	5·170	541·4	15·47	5·725	614·5	599·0
5	8·3	+ 8·5	5·262	541·3	16·47	5·815	613·5	597·0
6	7·8	+ 7·6	5·127	541·3	16·17	5·642	611·5	595·3
7	9·0	+ 8·6	5·178	541·0	18 74	5·592	603·0	584·3
8	10·3	+ 11·8	5·240	541·0	19·22	5·675	605·1	585·9
9	7·8	+ 7·6	5·220	541·0	19·21	5·738	613·8	594·6
10	11·9	+ 14·0	5·252	541·0	20·20	5·725	609·9	589·7
11	10·0	+ 11·4	5·152	541·0	20·31	5·557	602·7	582·4
12	11·5	+ 13·5	5·242	540·9	21·48	5·744	614·3	592·8
13	6·6	+ 5·2	5·271	540·8	21·72	5·761	611·9	590·2
14	5·3	+ 2·0	5·221	540·8	21·71	5·717	613·0	591·3
15	12·4	+ 14·7	5·200	540·4	23·05	5·694	615·4	592·4
16	8·3	+ 8·5	5·250	540·4	23·54	5·697	610·6	587·1
17	8·3	+ 8·5	5·195	540·3	22·81	5·626	609·7	585·9
18	8·6	+ 9·0	5·162	540·3	24·09	5·605	611·5	587·4
19	8·5	+ 8·9	5·216	540·3	24·10	5·676	611·7	587·6
20	13·1	+ 16·6	5·192	540·1	26·40	5·641	613·1	586·7
21	8·6	+ 8·3	5·085	540·0	27·57	5·523	614·1	586·5
22	7·2	+ 6·4	5·207	539·9	28·16	5·705	619·7	591·6

Table, No. 48.

HEAT OF STEAM BELOW ATMOSPHERIC PRESSURE.

STEAM.					WATER.			HEAT OF STEAM.		
Pressure.		Temperature.				Temperature.				
Milemetres of mercury.	Atmosphere of 14·706 lb.	Before condensation. Deg. Cent.	After condensation. Deg. Cent.	Quantity condensed.	Quantity in condenser.	Before the admission of steam.	After the condensation of steam.	Heat conducted to water, per min.	Total quantity.	Latent or diffused.
Mm.	Atm.	°	°	Grms.	Grms.	Cent.	Cent.	Cent.	Cent.	Cent.
488·75	0·643	88·11	19·62	1390·85	66538·2	6 82	12 8361	0·00350	633·4	545·3
483·31	0·636	87·83	17 90	1219·25	66545·4	6·65	11·2771	0·00350	633 1	545·3
449·84	0 592	85·97	20 33	1444·50	66737·8	7·20	13·2011	0·00350	628·4	542·0
437·16	0·575	85·21	19·2[illegible]	1404·00	66538·5	6·10	12·8977	0·00350	628·6	543·4
436 62	0 574	85·20	18 61	1278·98	66545 3	6·91	11·7868	0·00350	631·7	516·5
430 92	0·567	84 88	17·71	1216 65	66545·6	6·30	11·4730	0·09850	629·9	345·0
401·40	0 528	83·08	22·53	1310·63	66540·0	10 61	11·9472	0 00315	628 9	545·8
394·92	0 519	82·66	21·63	1378·34	66531·9	9 05	12·6276	0·00345	631·0	548·8
369·80	0·486	81·03	21·05	1338·45	66542·4	8·85	12·2286	0 00310	628 8	547·8
363 36	0·478	80·60	22·31	1243·87	66534·4	11·02	11·3202	0·00310	627 7	547·1
360·12	0·474	80·37	22·14	1230·15	66535·0	10 93	11·2189	0·00340	628·8	547·8
357·13	0·470	80·17	19·44	1244·23	66543·5	8·05	11·4240	0·00310	630·2	550·0
348·22	0·458	79·55	17·01	979·10	66543·5	8·03	9·0240	0·00240	630·1	550·5
330·63	0·435	78·28	17·67	1174·26	66538·1	7·00	10·7537	0·00340	627·0	548·7
307·17	0·404	76·50	20·20	1457·37	66545·3	6·95	13·3304	0·00340	628·6	552·1
247·07	0·325	71·35	20·28	1462 02	66538 1	7·09	13·2773	0·00340	624·4	553·0
244·55	0 322	71·11	18·28	1264·00	66538·2	6·93	11·4712	0·00320	622·2	551·1
238·09	0·313	70·19	18·69	1294·22	66545·3	6·93	11·8348	0·00320	626·9	556·4
230·17	0·303	69·70	19·17	1359·50	66545·3	6·85	12·4115	0·00320	626·4	556·7
213·72	5·281	68·01	19·12	1390·98	66538·4	6·59	12·6183	0·00320	622·5	554·5
198·10	0·270	66·30	18·23	1297·23	66545·5	6·48	11·8259	0·00320	624·7	558·4
181·47	0·239	64·34	19·58	1424·83	66538·4	6·73	12·9255	0·00320	622·9	558·6
170·91	0·224	63·02	18·25	1284·34	66545·5	6·58	11·7109	0·00320	625·5	562·5

Table, No. 49.

HEAT OF STEAM OF ATMOSPHERIC PRESSURE.

STEAM.					WATER.			HEAT OF THE STEAM.	
Pressure in		Temperature.				Temperature.			
Milemetres of Mercury.	Atmos-phere of 14·706lbs.	Before con-densation. Deg. Cent.	After con-densation. Deg. Cent.	Quantity condensed.	Quantity in condenser.	Before steam is admitted.	Increased after steam is con-densed.	Total of steam. Deg. Cent.	Diffused or latent. Deg. Cent.
Mm.	Atm.	°	°	Grms.	Grms.	Cent.	Cent.	°	Cent.
746·52	0·983	99·49	21·50	949·10	66524·0	12 81	8·7441	633·3	533·81
746·55	0·983	99·49	24·80	1255·15	66520·4	13·40	11·4829	634·1	534·61
767·06	1·009	100·26	22·85	1287·88	66534·4	11·00	11·8532	635·2	534·96
765·94	1·008	100·22	21·98	1200·79	66534·4	11·00	11·0485	634·0	533·78
770 13	1·013	100·37	..	1316·85	66538·6	6·19	12·1728	633·4	533·03
768·37	1·011	100·31	..	1413·45	66538·1	6·96	13·0710	635·4	535·09
746·43	0·982	99·49	23·71	1231·10	66523·5	13·00	11·3471	635·8	536·31
745·71	0·981	99·46	23·38	1230·10	66523·1	13·09	11·3356	636 3	536·84
741·29	0·975	99·31	23·53	1240·23	66523·3	13·05	11·4284	636·4	537·09
740·82	0·975	99·28	24·16	1233·05	66522·5	13·27	11·3744	637·6	538·32
765·19	1·007	100·19	22·37	1272·84	66535·4	10·76	11·7391	636 0	536·81
765·19	1·007	100·19	23·00	1308·85	66527·3	11·02	12·0794	636·8	536·61
765·23	1·007	100·19	23·03	1287·65	66526·2	11·26	11·9100	638·3	538·11
765·28	1·007	100·19	22·85	1275·57	66534·4	11·00	11·7908	637·9	577·71
765·20	1·007	100·19	21·63	1121·04	66526·2	11·27	10·3542	635·9	535·71
767·00	1·009	100·26	22·22	1274·57	66535·2	10·83	11·7613	635·9	535·64
767 03	1·009	100·26	22·38	1371·61	66526·7	11·14	12·6883	637·9	537·64
767·12	1·009	100·26	22·61	1369·23	66527·6	10·91	12·6666	637·9	537·64
767·02	1·009	100·26	20·92	1099·03	66533·4	11·23	10·1510	635·6	535·34
767·00	1·009	100·26	21·00	1120·99	66534·0	11·05	10·3599	635·8	535·54
767·09	1·009	100·26	23·81	1425·42	66526·2	11·29	13·1368	636·7	536·44
765·87	1·008	100·22	23·00	1425·58	66526·2	11·26	13·1702	637·6	536·38
765 72	1·008	100·22	21·45	1213·19	66535·0	10·88	11·2514	638·4	537·18
765·90	1·008	100·22	23·67	1376·68	66527·0	11·04	12·6904	636·8	536·58
765·92	1·008	100·22	22·00	1230·03	66534·9	10·90	11·3640	636·6	536·38
765·85	1·008	100·22	22·85	1321·87	66527·1	11·05	12·2085	637·2	536·98
770·10	1·013	100 37	18·79	1384·70	66545 8	6·03	12·8426	636·1	535·74
768·50	1·011	100·32	18·00	1266·75	66545·6	6·30	11·7818	636·7	536·38
768·47	1·011	100·32	19·37	1395·18	66538·5	6·51	12·9476	637·3	537·08
768·32	1·011	100·31	19·32	1351·70	66545·3	6·82	12·5640	636·1	535·79
766·19	1·008	100·22	16·03	1369·22	66544·2	4·13	12·7499	635·6	535·38
766·24	1·008	100·22	22·37	1956·04	66536·9	4·04	18·0614	636·9	536·68
767·15	1·009	100·26	18·36	1455·09	66544·9	4·64	13·5057	635·9	525·64
767·23	1·009	100·26	20·19	1612·69	66537·9	4·89	14·9242	635·9	535·64
735·76	0·968	99·09	18·89	1357·20	66545·6	5·67	12·5778	635·7	536 61
735·76	0·968	99·09	21·50	1772·29	66537·8	4·78	16·3707	636·1	537·01
735·09	0·967	99·07	18·02	1363·38	66545·6	5·64	12·6746	636·6	537·53
735·09	0·967	99·07	20·19	1575·64	66538·6	5·58	14·6091	636·9	537·83
742·87	0·977	99·36	18·16	1431·45	66543·3	3·77	13·2922	636·1	536·75
742·87	0·977	99·36	19·18	1619·65	66537·1	4·04	15·0354	636·8	537·46
742·08	0·976	99·33	16·86	1413·95	66544·2	4·12	13·1655	637·3	537·97
742·05	0·976	99·33	20·19	1691·20	66537·8	4·75	15·6584	636·4	537·07
740·53	0·974	99·27	19·03	1483·10	66545·0	4·81	13·7426	635·7	536·43
740·53	0·974	99·27	19·75	1590·50	66538·4	5·19	14·7505	636·8	537 58

Note.—Cent. × 1·8 + 32 = Fah.; Milemetre × ·03937 = inches; Grammes ÷ 453·544 = lbs. Heat conducted per minute = ·004° Cent.

Table, No. 50.

HEAT OF STEAM ABOVE ATMOSPHERIC PRESSURE.

STEAM.					WATER.			HEAT OF STEAM.		
Pressure.		Temperature.				Temperature.				
Milemetres of mercury.	Atmosphere of 14·706 lbs.	Before condensation. Deg. Cent.	After condensation. Deg. Cent.	Quantity condensed.	Quantity in condenser.	Before the admission of steam.	After the condensation of the steam.	Conducted to water per min.	Total quantity in steam.	Latent or diffused.
Mm.	Atm.	°	°	Grms.	Grms.	Cent.	Cent.	Cent.	Cent.	Cent.
1448·17	1·905	119·25	24·68	1156 27	66537 0	10 32	13 5190	0·00578	612 3	523·0
1462 73	1 924	119·60	19 72	1000·48	66536·9	10 37	9·3563	0 00578	611·8	522·2
1582·92	2 083	122·17	22 36	1253 75	66537·4	10 17	11 6780	0 00578	612·2	520 0
1742 81	2 293	125 2	18 12	1282 58	66545 8	6 07	12 0700	0 00600	643·9	518·7
1768 75	2·327	125 5	21·73	1669 45	66538 5	6 21	15·6032	0 00600	643·6	518 1
1849 26	2 433	127·2	18 16	1315 25	66545 8	5·94	12 3871	0 00600	641·8	517·6
1952·17	2·568	129 0	20 42	1517 46	66538 5	6 23	11·2464	0 00600	645·1	516 1
2285 26	3 007	131 4	25 27	1247 20	66527 1	12 35	11·6912	0 00600	619 0	514 6
2273·47	2 991	131·2	P5·27	1262 70	66526 6	12 47	11·8112	0·00600	647·5	513·3
2335·18	3 072	135 1	24 83	1234·23	66523 0	12 82	11 5716	0 00600	648·5	513·4
2325 68	3 060	135 0	21·39	1238 80	66523·0	12·79	11 6347	0·00600	649 1	514·1
2340·83	3 080	135 2	23 96	1235 50	66525 2	12 60	11·5833	0 00600	647·6	512·4
2365·94	3 113	135·5	18 76	1376 53	66545 4	5 24	12·9977	0·00600	647·0	511·5
2370 32	3 119	135 7	19 12	1188 95	66538 5	5 40	14·0530	0·00600	647·3	511·6
2426·85	3·193	136·4	21·25	1641·90	66538 7	5·81	15 4585	0 00600	647·6	511·2
2498 63	3 288	137 5	17 59	1212·75	66545 7	6·11	11·1794	0 00600	647·4	509 9
2517·90	3·313	137·7	19·69	1407·72	66538 4	6·38	13·2781	0·00600	647·2	509·5
2588·05	3·394	138 6	16 84	1211 70	66545·6	5·50	11·5038	0·00600	648·4	509·8
2842·03	3 739	142·0	17·32	1287·05	66541·9	4 81	12 2258	0 00650	649·2	507·2
2860·71	3 764	142 2	17 29	1339 02	66537·1	4 10	12·7136	0 00650	648·9	506·7
2911·75	3 831	142 5	16·19	1184·84	66541·4	3·01	11·2475	0 00650	647·8	505·3
2955·66	3 889	143·4	17·92	1353 60	66537·9	4·85	12 8699	0·00650	650·3	506·9
3042·51	4·003	144·3	22·95	1221·20	66534·4	10·99	11 5008	0·00620	649 4	505·1
3049 85	4 013	144 3	18 71	1145·32	66538 5	5·40	13·7108	0 00650	649·7	505·4
3116·00	4 100	145·3	24·51	1246·50	66528 3	12·11	11·7345	0 00620	651·0	505·7
3128·00	4·116	145·4	25 12	1291·00	66528 0	12·22	12·1253	0·00620	649·9	504·5
3149·25	4·144	145·6	24 51	1307·01	66527·6	12 26	12·2711	0 00620	649·1	503·5
3223·09	4 241	146·5	21·79	1208 80	66537·8	10·90	11 4335	0 00620	651·1	504·6
3323·69	4 373	147·6	24·13	1305·50	66531·8	11·58	12·2756	0·00620	649·6	502·0
3437·85	4·523	149 0	24 12	1299·00	66533·0	11·27	12·2761	0 00620	652·8	503·8
3565·81	4·692	150·2	23·96	1296 48	66534·3	11·04	12·2523	0 00620	652·6	502·4
3883·14	5·109	153·5	15·59	1144·95	66537·5	4·67	10·9170	0 00670	650 1	496·6
3945·55	5·191	154·1	18·70	1499·90	66544·6	4·52	14 2327	0 00670	650·2	496·1
4045·13	5·335	155·1	15·84	1338·14	66542·5	3·42	12·7840	0·00700	651·3	496·2
4067·81	5 352	155·2	18·36	1402·45	66537·7	4·76	13·3174	0 00700	650·0	494·8
4068·44	5·353	155·2	18·59	1490·45	66537·3	4·65	14·1941	0·00700	652·0	496·8
4070·52	5·357	155·3	16·42	1313·88	66543·2	3·71	12·5336	0·00700	651·0	495·7
4115·06	5 415	155·7	17·32	1269 90	66544·5	4·37	12·1007	0·00700	651·4	495·7
4195·56	5·520	156·5	15·84	1360·26	66541·0	3·16	13·0276	0·00805	652·9	496·4
4268·10	5·616	157·1	18·16	1518·13	66542·0	3·36	14·4533	0·00805	651·4	491·3
4350·09	5·724	157·8	17·52	1491·04	66541·4	3·01	14·2382	0·00805	652·0	494·2
4643 15	6·109	160·3	16·71	1280·25	66544·5	4·43	12·2476	0·00810	653·1	492·8
4653·75	6·123	160·4	18·89	1509·65	66537·9	4·85	14·4008	0·00810	653·4	493·0
4821·20	6·344	161·8	14·77	1038·70	66537·5	4·45	9·9838	0·00830	654·1	492·3
5182·11	6·818	164·6	17·77	1292·20	66545·5	5·42	12·3514	0·00830	653·6	489·0
5212·47	6·858	164·9	19·65	1459·05	66538·6	5·73	13·9473	0·00830	655·4	490·5
6127·67	8·062	171·6	17·14	1390·60	66544·2	4·13	13 3434	0·00850	655·5	483·9

STEAM.					WATER.			HEAT OF STEAM.		
Pressure.		Temperature.				Temperature.				
Milemetres of mercury.	Atmosphere of 14·706 lbs.	Before condensation. Deg. Cent.	After condensation. Deg. Cent.	Quantity condensed.	Quantity in condenser.	Before the admission of steam.	After the condensation of the steam.	Conducted to water per min.	Total quantity in steam.	Latent or diffused.
Mm.	Atm.	°	°	Grms.	Grms.	Cent.	Cent.	Cent.	Cent.	Cent.
6287·61	8·273	172·6	19·07	1522·15	66537·5	4·52	14·5716	0 00850	655 8	483·2
6298·49	8·287	172·6	17·52	1190 38	66538 7	6·09	11·4135	0 00850	655 3	482·7
6329·21	8·328	172·8	17·20	1241·32	66545·7	5·69	11·9120	0 00850	655·6	482·8
6366·87	8·380	173·8	19·05	1530·15	66537·5	4·47	14·6566	0·00850	656 1	483·0
6401·76	8·423	173·4	17·20	1347·65	66544·1	4·10	12 9418	0·00850	656·0	482·6
6478·81	8 524	173·9	17·73	1449·30	66536·4	3 86	13·9066	0 00860	655·9	482·0
6483·35	8·530	174·0	17·60	1353·48	66543·9	4·00	12·9904	0 00900	656·0	482·0
6702·83	8·819	175·3	17·71	1347·95	66545·0	4·83	12·9349	0 00900	656 1	480·8
6728·59	8 853	175·5	19·57	1520 88	66538 2	5·06	14·5565	0·00900	656 1	480·6
7350 02	9 671	179·3	18·59	1457·30	66543·8	3·95	14·0992	0 00950	662 3	483·0
7416·65	9 759	179·6	18·59	1387·83	66544·6	4·60	13·4219	0·00950	662·2	482 6
7420·62	9 764	179·6	19·20	1471·35	66538·2	4·98	14·2353	0 00950	662 7	483 1
7465·28	9 822	180·0	20·00	1552·06	66537·7	4·67	14 9825	0 00950	662·2	482·2
8056 49	10 600	183·2	18·88	1337·88	66545·4	5·17	12 9428	0 00950	662·4	479 2
8106·48	10 666	183·5	20·77	1478·64	66538·6	6·15	14·2713	0·00950	662·8	479·3
8131·26	10·699	183·7	19 75	1413·98	66538·6	5·76	13·6712	0·00950	662·8	479·1
8138·24	10 708	183·7	20·92	1614·90	66515·4	5·17	15·5494	0 00950	661·8	478·1
8550·41	11·250	186·0	20·22	1465 93	66538·5	5·64	14·2028	0·01000	664·5	478·5
8563·30	11·267	186·0	20·42	1440·52	66545·4	5 08	13·9510	0 01000	661 9	478 9
8925·38	11·744	187·9	20·60	1537·38	66538·4	5 36	14·8716	0 01080	664·4	476·5
8990·73	11·830	188·2	19·75	1474·39	66544·9	4·75	14·3140	0 01080	665·6	477·4
9004·86	11·848	188·2	21·73	1617·02	66538·4	5·36	15·6185	0·01080	664·2	476·0
10141·52	12·344	193·8	21·66	1427·75	66545·5	6·61	13·8296	0 01100	666·0	472·2
10193·27	13·412	194·2	22·13	1479·00	66544·4	7·48	14·2716	0 01100	664 3	470·1
10332·38	13·595	194·7	23 33	1585·73	66538·4	6·50	16 2719	0 01100	665 4	470·7
10354·84	13·625	194·8	20·48	1456·67	66545·8	5·93	14·1389	0 01100	666·0	471·2

As an example of conversion into English definitions, the last experiment in the table gives—

10354·84	M.m. × ·03937 in.	=407·67 in. mer. as the press. of the steam.
13·625	Atm. × 14·706 lbs.	=200·37 lbs. avoir. as the press. of the steam.
194·8	Cent. × 1·8 + 32	=382-64 deg. Fah. temp. of the steam.
20·48	Cent. × 1·8 + 32	= 68·86 deg. Fah. temp. of condensed steam.
1456·67	Grms. ÷ 453·544	= 3·21 lbs. of steam condensed.
66545·8	Grms. ÷ 453·544	=146·72 lbs. of water in the condenser.
5·93	Cent. × 1·8 + 32	= 42·67 Fah. temp. of water before steam con.
14·1389	Cent. × 1·8 + 32	= 57·45 Fah. temp. of water after steam con.
·011	Cent. × 1·8	= ·0198 Fah. conv. to water in conden. per min.
·666	Cent. + 1·8 + 32	=1230·8 Fah. total heat of the steam.
471·2	Cent. × 1·8 + 32	=880·16 Fah. diffused heat of the steam.

Note.—2·205 lbs. av. = 1 kilogramme.

39.37 lbs. av. = 1 metre.

The following table contains a few examples of the total heat of steam.

Table, No. 51.

TOTAL HEAT IN STEAM BY FORMULA.

For French definitions, total heat = 606·5 + temp. × ·305.

For English definitions, total heat = 1123·7 + temp. − 32 × ·305.

These rules are readily applied. For example, the total heat of steam of 446° Fah. is 446° − 32 × ·305 + 1123·7 = 1249·97 Fah., and of course the diffused heat is 1249·97 − 446 = 803.97 Fah.

For French definitions the total heat of steam of 230 Cent. is 230 × ·305 + 606·5 = 676·65 Cent., and 676·62 − 230 = 446·65 Cent. as the diffused heat.

STEAM.						HEAT.	
Temperature		Pressure.				Total.	
Cent.	Fah.	Milemetres of Mercury	Inches of Mercury.	Atmos of 14·706. lbs	lbs. per sq. inch.	Cent.	Fah.
°	°	Mm.	In.	Atm.		°	°
0	32	4·60	0·1811	0·006	·088	606·5	1123·70
10	50	9·16	0·3606	0·012	·176	609·5	1129·10
20	68	17·39	0·6816	0·023	·338	612·6	1134·68
30	86	31·55	1·2421	0·042	·617	615·7	1140·16
40	104	54·91	2·1618	0·072	1·058	618·7	1145·66
50	122	91·98	3·6212	0·121	1·779	621·7	1151·06
60	140	148·79	5·8578	0·196	2·882	624·8	1156·64
70	158	233 09	9·1767	0·306	4·500	627·8	1162·04
80	176	354·64	13·9621	0·466	6·853	630·9	1167·62
90	194	525·45	20 6869	0·691	10·161	633·9	1173·02
100	212	760·00	29·9212	1·000	14·706	637·0	1178·60
110	230	1075·37	42·3374	1·415	20·809	640·0	1184·00
120	248	1491·28	58·7116	1·962	28·853	643·1	1189·58
130	266	2030·28	79·9321	2·671	39·279	646·1	1194·98
140	284	2717·63	106·9930	3·576	52·886	649·2	1200·56
150	302	3581·23	140·9930	4·712	69·294	652·2	1205·96
160	320	4651·62	183·1342	6·120	90·006	655·3	1211·54
170	338	5961·66	234·7105	7·844	115·35	658·3	1216 94
180	356	7546·39	297·1013	9 929	146·01	661·4	1222 52
190	374	9442·70	371·7590	12·425	182·72	664·4	1227·92
200	392	11688·96	460·1943	15·380	226·17	667·5	1233·50
210	410	14324·80	560 9673	18·848	271·17	670·5	1238 90
220	428	17390·36	684·6584	22·882	336·50	673·6	1244·48
230	446	20926·40	823·8723	27·535	404·93	676·6	1249·97

The weight or density of steam is that of the water it contains, but the force and weight increase in different ratios, as seen in the following table. At 62° Fah. a gallon of water weighs 10 lbs. and measures 277·274 cubic inches, and a cubic foot of water is 1728 ÷ 277·274 = 62·321 lbs. Since the relative volume of steam of 14·706 lbs. force and 212 Fah. is 1700, the weight of 1 cubic foot of steam is 62·321 ÷ 1700 = ·03666 lbs. nearly. See Tables, Nos. 57 and 60.

To find the weight of a cubic foot of steam of any other force, divide 62·321 by the relative volume due to the pressure.

Table, No. 52.

RELATIVE TEMPERATURE, FORCE, AND WEIGHT OF STEAM FROM OTHER EXPERIMENTS.

Temp. Fah.	Force in Atmospheres.	Force in lbs.	Weight in Atmospheres.	Weight in lbs. per cubic foot.	Ratio of weight to force, weight being 1.
32°	·006	·088	·00028		
212	1·	14·706	1·	·03666	1·
230	1·412	20·764	1·375	·0504	1·02682
248	1·951	28·691	1·852	·0678	1·05364
266	2·652	39·00	2·451	·0898	1·08016
284	3·529	51·897	3·187	·1168	1·10728
302	4·647	68·338	4·098	·1502	1·13410
320	6·026	88·618	5·191	·1903	1·16092
338	7·687	113·04	6·472	·2372	1·18744
356	9·692	142·53	7·980	·2925	1·21456
374	12·111	178·10	9·756	·3576	1·24138
392	14·947	219·81	11·786	·4320	1·26820
410	18·283	268·87	14·118	·51756	1·29502
428	22·136	325·53	16·746	·6139	1·32184
446	26·526	390·09	19·669	·7210	1·34868

In 1837, Mr. Josiah Parkes made 28 experiments, on an ordinary locomotive boiler, to test practically how far the theory of the sum of the heat in steam, being the same at all temperatures, was to be relied on. Considerable care was taken to obtain accurate results, as given in Table, No. 53.

TABLE, No. 53.

SUMMARY OF MR. PARKES'S EXPERIMENTS ON THE HEAT OF STEAM.

Expts	Pressure.	Temp.	Coals.	Burnt.	Water.	Duration.	
No.	Above Atm. lbs.	Deg. Fah.	Total lbs.	Each ex. lbs.	Evapt. cub. ft.	h.	m.
4	0	212·	800	200	20	10	0
1	5	226·3	199	199	20	9	55
1	10	237·64	202	202	20	10	1
3	1	247·94	585	195	20	9	50
2	20	256·78	396	198	20	10	2
1	25	264·82	204	204	20	10	4
1	30	272·02	200	200	20	10	0
1	35	278·80	203	203	20	9	58
2	40	285·04	404	202	20	9	59
2	45	290·76	408	204	20	10	5
3	50	295·96	615	205	20	10	0
3	55	300·76	624	208	20	9	57
4	60	305·06	840	210	20	10	2

These really practical trials had evidently been conducted with great care, since they corroborate and confirm Regnault's more recent experiments—that the heat of steam increases with its pressure. However at the time Mr. Parkes himself drew the conclusion—that the heat of steam was constant at all pressures. The increase of coals required to evaporate the 20 cubic feet of water at the higher temperatures is obvious, but was attributed to the circumstances under which the trials were made. Had these experiments been as fairly dealt with as they had been carefully conducted, Mr. Parkes would have had the honour now claimed by M. Regnault, of submitting experimental proof of the increasing heat of steam.

These are a few of the leading expositions of steam which now engage attention; but other distinguished men—including Watt, Robinson, Southern, and Ure—have also given steam tables. Scarcely two of them correspond at any but the starting points; and, for reference, a number of them are comparatively arranged in the following tables.

TABLE, No. 54.

ELASTIC FORCE OF STEAM, BY VARIOUS AUTHORITIES, FROM — 22°, 22° TO 212° TEMPERATURE.

Temp.	Dalton.	Watt.	Robinson.	Southern.	Ure.	Tredgold.	Pambour.	Regnault.
Fah.	In. Mer.	In. Mer.	In. Mer.	In. Mer.	In. Mer.	In. Mer.	In. Mer.	In. Mer.
22	..	..	..	..	..	..	..	·013
4	..	..	..	..	..	..	..	·035
0	..	..	..	..	..	..	..	·081
14	..	..	..	..	..	..	..	..
24	..	..	..	..	·17	·118	..	..
32	·2	..	·0	·16	·2	·172	..	·18
40	·26	..	·1	..	·25	·245	..	..
42	·28	..	..	·23	..	·266	..	..
50	·37	..	·2	..	·36	·37	..	·36
52	·4	..	..	·35	..	·401	..	..
55	·44	·15	..	..	·416	·45	..	..
60	·52	..	·35	..	·516	·55	..	..
62	·56	..	..	·52	..	·587	..	..
68	..	..	..	..	..	..	..	·68
70	·72	..	·55	..	·72	·78	..	..
72	·77	·64	..	·73	..	·842	..	..
80	1·0	..	·82	..	1·01	1·106	..	1·03
82	1·07	·81	..	1·02	..	1·182	..	..
86	1·21	..	..	..	..	..	..	1·24
90	1·36	..	1·18	..	1·36	1·53	..	..
92	1·44	1·21	..	1·42	..	1·639	..	..
100	1·86	..	1·6	..	1·86	2·08	..	..
102	1·98	..	..	1·96	..	2·21	..	..
103	2·04	..	..	..	..	..	2 0	..
104	2·11	1·75	..	..	2·07	..	..	2·16
110	2·53	..	2·25	..	2·45	2·79	..	..
112	2·86	..	..	2·66	..	2·95	..	..
118	3·16	2·68	..	..	..	3·59	..	..
120	3·33	..	3	..	3·3	3·68	..	..
122	3·5	..	..	3·58	3·9	3·89	..	3·62
126	3·89	3·57	..	..	..	..	4	..
130	4·34	3·63	3·95	..	4·36	4·81	..	..
132	4·60	..	..	4·71	..	5·07	..	..
140	5·74	..	5·15	..	5·77	6·21	..	5·85
141	5·9	..	..	..	..	..	6	..
142	6·05	5·46	..	6·10	..	6·53	..	..
145	6·53	..	..	..	6·6	..	..	6·7
148	7·05	6·40	..	..	..	..	..	7·19
150	7·42	..	6·72	..	7·53	7·94	..	..
152	7·81	..	..	7.9	..	8·33	8	8·2
154	8·2	7·4	..	..	..	..	..	8·5

Temp.	Dalton.	Watt.	Robinson.	Southern.	Ure.	Tredgold.	Pambour.	Regnault.
Fah.	In. Mer.	In. Mer.	In. Mer.	In. Mer.	In. Mer.	In. Mer.	In. Mer.	In. Mer.
157	8 81	8·25	..	..	..	..	..	9·0
158	9·02	..	..	..	..	..	..	9·17
159	9·24	..	..	..	..	..	..	9·39
160	9·46	..	8·65	..	9·6	10·05	..	9·66
161·4	9·7	9.2	..	..	..	..	10	..
162	9 91	..	..	10·05	..	10·52	..	..
169·2	11·89	..	..	..	..	..	12	12
170	12·13	..	11·05	..	12·05	12·6	..	..
172	12·73	11·95	..	12·72	..	13·17	..	..
173	13·18	..	..	..	..	13·46	..	13·06
175	13·62	12·88	..	..	13·55	..	..	13·68
176	13·92	..	..	..	..	..	14	13·96
178	14·52	13·9	..	..	..	..	..	14·60
180	15·15	14·71	14·05	..	15·16	15·67	..	15·30
182	15·86	16 58	..	16·01	16.9	16·35	16	15·92
185	17·0	17·51	..	..	..	..	..	17·09
187	17·8	..	..	..	..	..	18	17·88
190	19·0	..	17·85	..	19	19·35	..	19·29
192·4	20·01	..	..	..	..	..	20	..
194	20·77	..	..	..	21·06	..	..	20·68
197	22·13	21·37	..	..	..	..	22	..
200	23·64	..	22·62	..	23.6	23·71	..	..
201·3	24·24	..	..	..	..	..	24	..
205·3	26·29	..	..	..	26·1	..	26	..
209	28·29	..	..	..	..	..	28	..
212	30	30	30	30	30	30	29·92	29·92

Table, No. 55.

ELASTIC FORCE OF STEAM, BY VARIOUS AUTHORITIES, FROM 212° TO 320°.

Temp.	Taylor.	Ure.	Tredgold.	Franklin Institute.	French Academy.	Pambour.	Regnault.
Fah.	In. Mer.	In. Mer.	In. Mer.	In. Mer.	In. Mer.	In. Mer.	In. Mer.
212	30	30	30	30	29·92	29·92	29·92
216·4	32·6	33·4	..	..	..	32	..
220	35	35·54	34·92	..	..	34·2	..
222·6	36·64	..	..	..	..	36	..
225	38	39·11	38·32	..	..	..	..
225·6	38·4	39·55	..	..	..	38	..
228·3	40·4	41·50	..	..	..	40	..

Temp.	Taylor.	Ure.	Tredgold.	Franklin Institute.	French Academy.	Pambour.	Regnault.
Fah.	In. mer.	In. mer.	In. mer.	In. mer	In. mer.	In. mer.	In. mer.
230·	41·55	43·10	42·	..	..	..	42·27
231·	42·25	43·9	..	..	..	42·	..
233·6	44·25	..	..	..	..	44·	..
234·	44·6	46·4	..	43·05	45·	..	..
235·	45·5	47·22	..	45·	..	..	..
236·4	46·49	..	..	..	..	46·	..
238·4	48·56	50·28	..	..	..	48·	..
239·25	49·35	..	..	47·34	..	..	..
240·	50·	51·7	50·24	..	..	..	..
240·7	50·62	..	..	..	..	50·	..
243·	52·62	..	..	..	..	52·	..
245·1	54·49	56·38	..	52·1	..	54·	..
246·5	55·16	..	..	..	..	..	57·15
247·2	56·44	..	..	..	..	56·	57·7
248·	57·20	59·9	..	..	..	..	58·61
249·2	58·40	..	..	..	..	58·	..
250·	59·12	61·9	59·79	60·	..	..	..
250·5	59·62	..	..	..	60·	..	..
251·	60·10	..	..	..	..	60·	..
252·	61·12	..	..	..	..	..	63·
253·1	62·31	..	..	..	..	62·	..
255·	64·4	67·25	..	..	..	64·	..
256·25	65·73	..	..	65·37	..	..	..
256·8	66·4	..	..	..	..	66·	..
257·36	67·1	69·70	..	..	..	..	68·79
258·6	68·45	..	..	..	..	68·	..
260·	70·12	72·3	..	70·8	..	..	..
260·3	70·45	72·7	..	..	..	70·	..
260·96	..	..	..	..	..	..	72·99
261·	71·25	..	72·	..	..	..	..
262·	72·45	74·9	..	72·9	..	72·	..
263·8	74·45	..	..	..	75·	74·	..
264·	74·8	..	..	75·	..	..	77·
265·3	76·38	78·40	..	..	..	76·	..
266·	77·25	..	..	..	..	..	79·88
266·9	78·38	81·89	..	..	..	78·	..
268·4	80·33	..	..	..	..	80·	..
270·5	82·5	86·3	83·45	81·	..	82·	..
271·	83·9	..	..	82·56	..	..	..
271·4	84·4	88·17	..	..	..	84·	..
272·	85·45	..	86·2	..	..	..	..
273·	86·95	90·71	..	..	..	86·	89·2
274·	88·5	..	..	..	..	..	90·33
275·	90·	93·48	..	90·	90·	88·7	91·8
275·7	91·05	94·6	..	..	..	90·	..

Temp.	Taylor.	Ure.	Tredgold.	Franklin Institute.	French Academy.	Pambour.	Regnault.
Fah.	In. mer.	In. mer.	In. mer.	In. mer.	In. mer.	In. mer,	In. mer.
276·26	92·0	..	..	..	..	..	93·57
277·1	93·3	97·01	..	..	92·	92·	95·2
278·4	95·3	..	..	94·41	..	94·	..
279·7	97·2	101·8	..	..	..	96·	98·9
280·	97·75	101·9	97·92	..	..	..	..
281·	99·25	..	..	..	..	98·	..
282·	100·7	104·68	..	..	..	..	102·12
282·3	101·15	..	..	..	..	100·	..
283·6	103·1	107·98	..	..	..	102·	..
284·	103·8	..	..	105·	..	102·8	106·71
284·8	104·4	..	..	109·65	110·8	104·	..
286·	107·3	..	..	112·62	..	106·	..
287·2	109·14	114·8	..	..	..	108·	111·95
288·5	111·7	..	..	..	..	110·18	114·93
290·7	116·	120·15	115·6	119·75	..	114·	..
291·9	118·1	..	..	..	..	116·	120·76
293·	120·25	..	..	121·5	..	118·	..
293·72	121·68	..	120·93	..	126·	..	123·48
294·1	122·40	126·9	..	128·11	..	120·	..
295·	124·15	129·	123·5	..	..	122·2	127·22
295·9	125·85	130·9	..	131·21	..	124·	..
297·	128·	133·7	..	..	..	126·	..
297·68	122·2	..	..	..	..	..	131·19
298·5	130·7	137·0	..	135·8	..	128·7	..
299·1	131·8	..	..	141·9	..	130·	..
300·	133·75	139·7	133·2	142·6	..	131·82	135·51
302·	137·55	144·3	..	144·33	..	135·6	140·6
303·5	140·82	147·1	..	146·72	..	138·6	..
304·2	142·3	..	..	150·3	..	140·	..
305·5	145·12	151·16	..	154·28	..	142·78	..
308·	150·65	157·7	..	..	151·07	148·	152·97
310·	155·	161·3	154·5	165·	..	152·2	157.23
311·7	157·	166·32	..	..	..	156·	160·86
312·6	160·83	..	160·3	..	..	158·	162·45
314·0	164·20	..	..	..	164·8	161·8	166·27
314·75	166·1	..	..	181·23	..	..	168·48
316·04	169·15	..	..	..	..	166·	171·7
317·8	173·78	..	..	186·36	..	170·	..
319·75	178·98	..	..	197·13	179.25	174·84	174·87
320·75	181.6	..	..	193·92	..	..	183·70

Note.—The French Academy pressure has been rendered by taking each atmosphere as equal to 30 in. mer.

Table, No. 56.

ELASTIC FORCE OF STEAM BY VARIOUS AUTHORITIES, FROM 321° TO 510° TEMPERATURE.

Temperature.	Franklin Inst.	French Aca.	Pambour.	Regnault.
Fah.	In. mer.	In. mer.	In. mer.	In. mer.
321·	195·	..	178·	..
323·24	..	..	183·5	190·32
326·26	210·5	195	191·5	..
327·75	219·14	..	194·9	..
328 28	..	..	196·5	204·54
329·75	232·62	..	200·2	..
331·7	..	210	..	..
333·2	..	..	210	..
334·5	240·48	..	..	..
336·86	..	225	..	..
338·75	248·92	..	..	239
340·	255·	..	..	..
340·5	257·5	..	..	..
340·88	258·16	..	..	241·86
341 78	..	240	..	..
342·68	..	..	..	248·19
343·3	..	..	240	249·12
343·58	..	..	..	251·44
343·6	..	..	..	252·69
344·12	..	..	..	252·69
345·02	267·6	..	..	255·72
348·	278·33	..	..	265·9
349·	285·	..	..	..
350·	290·35	..	..	..
350·78	..	270	..	..
352·	297·36	..	..	..
352·4	300·	..	270	..
354·74	..	..	..	290·13
355·28	..	..	..	292·92
356·	..	..	..	294·66
358·8	..	300	..	..
360·8	..	..	300	..
361·76	..	..	..	319·98
361·23	..	..	..	320·97
366·8	..	330	..	338·01
368·5	..	..	330	..
370·56	..	..	..	354·9
374·	..	360	..	371·18
375·6	..	..	360	..
380·66	..	390	..	..
380·84	..	..	..	400·32

Temperature.	Franklin Inst.	French Aca.	Pambour.	Regnault.
Fah.	In. mer.	In. mer.	In. mer.	In. mer.
381·56	..	..	..	402·36
382·3	..	..	390	..
382·64	..	..	..	408·75
386·94	..	420	..	..
388·6	..	..	420	..
392·86	..	450	..	460·19
394·6	..	..	450	..
398·48	..	480	..	..
400·2	..	..	480	..
403·82	..	510	..	..
408·92	..	540	..	..
410·	..	..	..	563·3
413·78	..	570	..	..
418·46	..	600	..	..
423·	..	630	..	..
427·28	..	660	..	..
429·	..	678	..	..
431·4	..	690	..	..
435·5	..	720	..	..
439·3	..	750	..	..
446·	..	824	..	..
457·16	..	900	..	..
472·73	..	1050	..	..
486·59	..	1200	..	..
499·136	..	1350	..	..
510·6	..	1500	..	..

It is seen above that, at a temperature of 510·6°, water as steam acquires an elastic force equal to the pressure of a column of mercury 1500 inches high. Its elastic power is the source of its danger, for it would expand to fill about 340 times its original space at atmospheric pressure. Suddenly released, as in boiler explosions, its elasticity gives it a gun-powder-like force, and the fracture gives a gun-like direction to its recoil. Water of the same pressure in a hydraulic press would only expand about $\frac{1}{30}$th part of its volume, or $\frac{1}{20000}$th part of its volume per atmosphere of pressure.

Laws of Steam.

This summary of the experimental researches into the properties of steam shows, as might reasonably be expected, that there are different values placed upon the force of steam of a given temperature. These differences have led to various laws or formulæ being submitted, whereby to find the force from the temperature, or *vice versâ*, both by the experimenters and by others, such as Biot, Hann, Tate, and Rankine, who have reviewed their experimental labours.

At best these laws only give approximations to practical results, but as they are useful in calculating the theoretical values of steam, a few of the principal ones will be given. They are all based on the same general plan, only varying in their constants and co-efficients. Many of them involve so complex quantities to be raised to the fifth or sixth powers, or to have their fifth or sixth root extracted, that, arithmetically, they are rarely attempted to be solved. By logarithms, however, their solution is comparatively easy, as will be shown by an example.

To find the pressure of steam from its temperature, and the temperature from its pressure.

RULES OR FORMULÆ BY DIFFERENT AUTHORITIES.

For pressures from zero up to 48 inches of mercury.

Southern:—

$$\text{Press.} = \cdot04948 + \left(\frac{51\cdot3 + \text{temp.}}{155\cdot7256}\right)^{5\cdot13} \text{ for ins. of mercury.}$$

$$\text{Log pr.} = 5\cdot13 \text{ log.} (\cdot0064216 \text{ temp.} + \cdot329426) \text{ for lbs. per sq. in.}$$

$$\text{Temp.} = (155\cdot7256 \text{ press.} - 04948)^{\frac{1}{5\cdot13}} - 51\cdot3.$$

$$\text{Log temp.} = \text{log.} (\text{press.} - 04948)^{\frac{1}{5\cdot13}} + \text{log. } 155\cdot7256 - 51\cdot3.$$

Pressures from 10 to 120 inches of mercury.

Tredgold:—

$$\text{Press.} = \frac{\text{temp.} + 100^6}{177} \text{ for ins. of mercury.}$$

$$\text{Log pr.} = 6 \text{ log. } (\text{temp.} + 100) - 2\cdot247973 \text{ for ins. of mercury.}$$

Temp. = 177 press. $^{\frac{1}{6}}$ − 100.

Log temp. = log. (press. 2·247973) − 100.

Mellet:—

$$\text{Press.} = \frac{\text{temp} + 103^6}{201{\cdot}18.}$$

Log press. = 6 log. (·0049707 temp. + ·511979)^5.

Temp. = 201·18 press. $^{\frac{1}{6}}$ − 103.

Log temp. = log. (201·18 + log. press. $^{\frac{1}{6}}$ − 103.

For pressures from 60 lbs. to 360 lbs. per square inch.

French Academy:—

Log press. = 5 log. (·00680309 temp. + ·26974).

Press. = (·00680309 temp. + ·26974)^5.

Temp. = 146·992, pressure $^{\frac{1}{5}}$ − 39·6436.

Log temp. = log. (press. $^{\frac{1}{5}}$ + log. 146·992) − 39·6436.

Pambour:—

$$\text{Press.} = \left(\frac{98{\cdot}806 + \text{temp.}^6}{198{\cdot}562}\right)$$

Log press. = 6 log. (·0050362 temp. + 497608).

Temp. = 198·562 press.$^{\frac{1}{6}}$ — 98·806.

Log temp. = log. (198·562 + log. press.$^{\frac{1}{6}}$) — 98·806.

Franklin Institute:—

Press = (·00333 temp. + 1)^6 = atmospheres of 30 in. mer.

Log press. = 6 log. (·00333 + 1).

$$\text{Temp.} = \frac{\text{pressure}^{\frac{1}{6}} - 1}{{\cdot}00333}.$$

By log. = log. (press. −) — ·00333.

By substituting the respective exponents for each formula one or two given in words at length will apply to the others.

Taking that of the Franklin Institute, as one of the simplest form, adapted to recent experiments, it may be thus ex-

RULE.—Multiply the excess of the temperature above 212° by ·00333, and add 1 to the product. This sum raised to the 6th power gives the pressures in atmospheres.

Example.—Required the pressure of steam whose temperature is 302°.

302 − 212 = 90° above atmospheric pressure.
and 90 × ·00333 + 1 = 1·2997
1·2997

90979
116973
116973
25994
12997

2nd power = 1·68922009
1·2997

1182454063
1520298081
1520298081
337844018
168922009

3rd power = 2·1954793350973
1·2997

15368355456811
19759314158757
19759314158757
4390958701946
2195479350973

4th power = 2 8534645124596081
1·2997

199742515872172567
256811806121364729
256811806121364729
57069290249192162
28534645124596081

5th power = 3 70864782684375264757
1·2997

2596053478790626853299
3337783044159377382813
3337783044159377382813
741729565368750529514
370864782684375264757

6th power = 4·820129580548852316046729 = 4·82 atmosph.

and 4·82 × 14·75 = 71·09 lbs. per square inch, as the pressure by this rule.

By arithmetic, as this example indicates, the application of these rules is not very inviting, but by logarithms it is comparatively easy; hence their great advantage for such calculations.

By logarithms the rule is—Multiply the excess of the temperature above 212° by ·00333, and add 1 to the product. The logarithm of the sum, multiplied by 6, gives a logarithm whose natural number indicates the pressure in atmospheres.

Taking the same example, we have—

$$302° - 212° = 90 \times \cdot 00333 + 1 = 1 \cdot 2997,$$

$$\text{and log. of } 1 \cdot 2997 = 0 \cdot 113843 \times 6 = \cdot 683058,$$

and the natural number of ·683058 = 4·82 atmospheres as before.

For the French Academy formula multiply the temperature by ·0068030̸9, and add ·26974 to the product, which sum raised to the fifth power gives the pressure in lbs. per square inch, and in like manner for the others, by substituting the respective exponents for those given in this example.

By logarithms it is—Multiply the temperature by ·0068309, and add ·26974 to the product. Multiply the logarithm of this sum by 5 for a logarithm, whose natural number gives the pressure in lbs. per square inch.

It will be unnecessary to weary the reader with another arithmetical solution more extensive than the last, when a logarithmetical one is preferable. Taking the last example, by this rule we have

·0068309 × 302° (temp.) + 26974 = 2·32427, whose log. = 0·36629 × 5 = 1·83145, and the natural number of 1·83145 = 66·55 lbs. per square inch for the equivalent pressure by this rule, or 4·54 lbs. per inch less than the formula of the Franklin Institute.

Franklin Institute formula.—From the sixth root of the pressure in atmospheres subtract 1, and divide the remainder by ·00333 for the temperature above 212°.

By logarithms.—Divide the logarithm of the pressure in atmospheres by 6, and from the natural number of the remainder deduct 1. From the logarithm of this last remainder subtract the logarithm of ·00333, for a logarithm whose natural number gives the excess of temperature above 212°.*

Example.—Required the temperature of steam whose pressure is 4·82 atmospheres.

By logarithms, we have

$$\text{log. of } 4{\cdot}82 \div \frac{0{\cdot}683047}{6} = 0{\cdot}113841, \text{ whose natural number}$$
$$= 1{\cdot}2996 - 1 = {\cdot}2996, \text{ and}$$

log. of ·2996 = ·476542
log. of ·00333 = $\bar{2}$·522444

nat. num. of 3·954098 = 89·97° temperature,

which added to 212 = 301·97°, or within ·03 of a degree of the temperature given in the first example.

French Academy.—Multiply the 5th root of the pressure in lbs. per square inch by 146·992, and from this product deduct 39·6436, the remainder will give the temperature in deg. of Fah.

Or by logarithms.—To one fifth of the logarithm of the pressure add the logarithm of 146·992, or (2·1672937), and from the natural number of the logarithm of this sum deduct 39·6436 for the temperature in deg. of Fah.

Example.—Required the temperature of the steam whose pressure is 66·55 lbs. per square inch.

By logarithms:

$$\text{log. of } 66{\cdot}55 = \frac{1{\cdot}823148}{5} = 0{\cdot}3646296$$
$$\text{add log. of } 146{\cdot}992 = \quad = 2{\cdot}1672937$$
$$\text{and natural number of } 2{\cdot}5319233 = 340{\cdot}9$$

* See Law's Rudimentary Logarithms.

and 340·9 − 39·6436 = 301·256° temp., or only ·74 less than the temperature given to find the pressure of 66·55 lbs.

TO FIND THE TOTAL HEAT DIFFUSED IN STEAM FROM THE TEMPERATURE.

Rule for Regnault's experiments :—

Total heat = 305 temp. + 606·5 for deg. Cent.

„ = 305 (temp. − 32) + 1123·7 for deg. Fah.

Example.—Required the total heat of steam whose thermometeric heat is 212° Fah., or 100° Cent.

For Fah. 212 − 32 × ·305 = 54·9, and

54·9 + 1123·7 = 1178·4°

For Cent. 100 × ·305 + 606·5 = 637° Cent.

TO FIND THE DIFFUSED HEAT FROM THE TEMPERATURE.

Diffused heat = 305 temp. + 506·5 for deg. Cent.

„ = 305 (temp. − 32) + 911·7 for deg. Fah.

Example.—Required the diffused heat of steam whose temperature is 320° Fah. or 160° Cent.

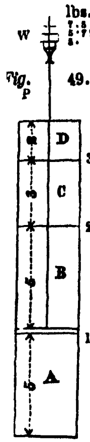
For Fah. 320° − 32 × 305° + 911·7 = 999·54°

For Cent. 160 × 305 + 506·5 = 555·3 Cent.

EXPANSIVE FORCE OF STEAM AND OTHER ELASTIC FLUIDS.

THE expansive force of steam is now extensively employed, and greatly contributes to the economy of the modern steam engine. It is usual to estimate this force by the laws of air as defined by Boyle and Mariotte. These laws are simple and may be thus expressed :—

The pressure or force of a confined elastic body is in the ratio of the space in which it is confined, hence the contents of any given space containing an elastic fluid, multiplied by the pressure of that fluid, will be a constant quantity of force, and its pressure in any other space will be that constant quantity, divided by the contents of the space into which the fluid has entered; or its force is inversely as its space.



For example, let the fig. No. 49 represent a cylinder 15 inches long and one square inch area, fitted with a piston P, and the part A, 5 inches long, filled with steam or air of 15 lbs. pressure, and the space B C D a vacuum. Now, if the weight or resistance W, on the piston rod, balance the 15 lbs., the piston will be stationary at 1; but if a weight of 7·5 lbs. is removed, the balance will be destroyed, and the piston ascend by the expanding force of the confined steam or air in A, until a balance of pressure again takes place. Suppose this is at 2, the piston will have moved 5 inches, and the steam or air will occupy double the space it did in A, with only half its original pressure, for the original pressure 15×5 in. space $= 75$ for the constant quantity, and $75 \div$ by the space A B = 10 ins. gives 7·5 lbs. as the expansive force in A B.

If another weight is removed of 5·77 lbs., the expanding air or steam will again raise the piston as before; and if it become stationary at 3, the space A B C will be equal to 13, and the constant quantity $75 \div 13 = 5{\cdot}77$ lbs. is the pressure exerted in the space A B C. If the last weight is removed, the expanding air will raise the piston to the top and occupy a space of 15 inches, or three times its original space, still giving out a force $= 75 \div 15 = 5$ lbs. per square inch.

These results may be thus stated:—

The space A B : the space A :: the force in A : the pressure A B;
for 10 : 5 :: 15 : 7·5, the pressure in A B = 1st expansion.

The space A B C : the space A B :: the force in A : the pressure A B C;
for 13 : 5 :: 15 : 5·77, the pressure in A B C = 2nd expansion.

The space A B C D : the space A B C :: the force in A : the force in A B C D;
for 15 : 5 :: 15 : 5, the pressure in A B C D = 3rd expansion.

Compression is the converse of expansion, and the pressure would be in the ratio of the compressing force.

Thus to compress the air into its original space of 5 inches again, we have $15 \times 5 = 75$ as the constant quantity, and

$75 \div 13 = 5{\cdot}77$ lbs. = 1st compressing force.
$75 \div 10 = 7{\cdot}5$ lbs. = 2nd compressing force.
$75 \div 5 = 15{\cdot}$ lbs. = 3rd compressing force.

This example of elasticity will show that the pressure or force in the original space, is to the force in the other spaces, as the contents of each of these spaces are to the contents of the original space, and explains the general law of air, as applied to ordinary steam.

The theoretical line C G, which diagrametically represents the ratio of expanding pressure is found to be a hyperbolic curve, as shown in Fig. No. 50, which represents a cylinder of 12 square inches area and 24 inches long, divided into 24 equal parts.

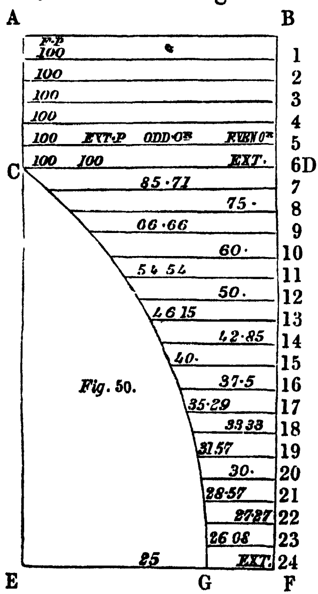


Fig. 50.

Full press. = 600
Extreme press. = 125
Odd ordinate press. = 414·57
Even „ „ = 355·95

Ex. Let each line of division, 1, 2, 3, 4, &c., represent the position of a piston impelled by air or steam, having a pressure of 100 lbs. per sq. inch, and cut off at one-quarter stroke; required, the mean pressure throughout the stroke, the mean pressure throughout the expansive portion of the stroke, and the pressure at each separate ordinate of division during the expansive action.

The rectangular part of full pressure A B C D × by the hyperbolic logarithm of the ratio (4) of expansion being = to the area of the rectangular hyperbola C D G F, we have for the mean pressure throughout the stroke,

Hyp. log of 4 = 1·386 × 6 (full pressure part) = 8·316 as the area of the space C D E F, which multiplied by the pressure 100 = 831·6, and ÷ 18 (the number of the spaces) = 46·2 lbs. per square inch as the mean pressure of expansion; and throughout the cylinder the full pressure = 6 parts × 100 (pressure) = 600 + 831·6 (expansive pressure) = 1431·6 ÷ 24 spaces = 59·65 lbs. as the mean pressure throughout the stroke.

The mean pressure throughout the cylinder may be found more readily by considering the full pressure part as 1, or the unit of the ratio of expansion, and adding it to the hyp. log. of the ratio. This sum, multiplied by the pressure and divided by the ratio of expansion, will give the mean pressure. Thus hyp. log. of 4 = 1·386 + 1 = 2·386 × 100 ÷ 4 = 59·65 lbs. as before.

If instead of multiplying by the pressure and dividing by the ratio of expansion, the sum 2·386 is multiplied by the extreme pressure of 25 lbs. or 100 ÷ 4 = 25, it is obvious that the result will be the same.

Table, No. 59, contains Napierian (often called hyperbolic) logarithms for calculating expansive steam power, as in this example.—See Page 215.

The base of the Napierian logarithms, still used in the highest branches of mathematical analysis, is 2·71828, whose asymptotes are at right angles to each other; but the base of the Briggean logarithms, used in all ordinary calculations, is 10, whose asymptotes make an angle of 25·7404° to each other.

For the pressure at each ordinate of expansion: By the law of expansion we have 6 × 100 for the constant quantity expanding to fill from 6 to 24 successively increasing spaces, hence—

Full pressure 6 spaces × 100÷6 = 100 lbs. mean pressure, and for expansion,

As 7 spaces	: 6 spaces	:: 100 lbs. press.	: 85·71 lbs. press. at	1st exp. ord.
8 ,,	: 6 ,,	:: 100 lbs. ,,	: 75· ,,	2nd ,,
9 ,,	: 6 ,,	:: 100 lbs. ,,	: 66·66 ,,	3rd ,,
10 ,,	: 6 ,,	:: 100 lbs. ,,	: 60· ,,	4th ,,
11 ,,	: 6 ,,	:: 100 lbs. ,,	: 54·54 ,,	5th ,,
12 ,,	: 6 ,,	:: 100 lbs. ,,	: 50· ,,	6th ,,
13 ,,	: 6 ,,	:: 100 lbs. ,,	: 46·15 ,,	7th ,,
14 ,,	: 6 ,,	:: 100 lbs. ,,	: 42·85 ,,	8th ,,
15 ,,	: 6 ,,	:: 100 lbs. ,,	: 40· ,,	9th ,,
16 ,,	: 6 ,,	:: 100 lbs. ,,	: 37·5 ,,	10th ,,
17 ,,	: 6 ,,	:: 100 lbs. ,,	: 35·29 ,,	11th ,,
18 ,,	: 6 ,,	:: 100 lbs. ,,	: 33·33 ,,	12th ,,
19 ,,	: 6 ,,	:: 100 lbs. ,,	: 31·57 ,,	13th ,,
20 ,,	: 6 ,,	:: 100 lbs. ,,	: 30· ,,	14th ,,
21 ,,	: 6 ,,	:: 100 lbs. ,,	: 28·57 ,,	15th ,,
22 ,,	: 6 ,,	:: 100 lbs. ,,	: 27·27 ,,	16th ,,
23 ,,	: 6 ,,	:: 100 lbs. ,,	: 26·08 ,,	17th ,,
24 ,,	: 6 ,,	:: 100 lbs. ,,	: 25· ,,	11th ,,

Exp. 18 spaces and 795·92 ÷ 18 = 44·2 lbs. as the arithmetical mean of expansive pressure.

These values give the pressure at each separate line of expansion, yet the arithmetical mean only represents the mean of rectangular spaces, but does not include the curved portion at the end of each rectangle, and gives a mean 2 lbs. less than the real mean found by hyp. logarithms. The full pressure being the same in both cases, the mean difference is less than the expansive difference, for 600 × 795·92 ÷ 24 = 58·14 lbs. as the mean arithmetical pressure throughout the cylinder, or 1·51 lb. less than the real mean.

The contrary would take place with compressed steam, as each rectangle would contain a space beyond the curved line, and thus give the pressure in excess. A near approximation is obtained by adding together the two extreme pressures;

4 times the sum of the *even* ordinates (8, 10, 12, etc.), and twice the sum of the *odd* ordinates (7, 6, 11, etc.). This sum multiplied by the common distance, and divided by 3, gives the force of expansion nearly; thus referring to the diagram, No. 50.

The extreme pressures	= 100· + 25 =	125·
The even ordinates	= 355·95 × 4 =	1423·8
The odd ordinates	= 414·37 × 2 =	829.14

$$\frac{2377{\cdot}94}{3} = 792{\cdot}65 \text{ lbs.}$$

as the amount of the expansive pressure, and $\frac{792{\cdot}65+600}{24} =$ 58·02 lbs., or 1·63 less than by hyp. logarithms.

A summary of these methods of calculation will show their comparative approximation.

Hyperbolic	method	= 59·65 lbs.
Ordinate	„	= 58·02 „
Arithmetical	„	= 58·14 „

Either method may therefore be used, according to the degree of accuracy required, for with working steam the effect of losing temperature, or of condensation, would cause the result to be less than the hyperbolic mean.

Double Cylinder Expansion.

This plan of working stationary engines with high-pressure steam in a small cylinder, and then expanding it to work another piston in a larger cylinder communicating with a condenser, is now found to be a very useful one.

It is on this plan that Mr. Adams proposes his cylinders for locomotive engines.

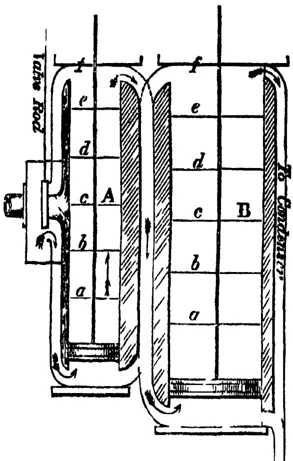


Fig 51.

Let fig. No. 51 represent two such cylinders, of which the smaller, A, is 6 cubic feet in capacity, and the larger, B, of 24 cubic feet capacity, or in the ratio of 1 to 4. The first cylinder, A, receives the steam, say of 40 lbs. pressure per square inch from the boiler, and the second cylinder, B, receives the steam, as indicated by the respective arrows, from the cylinder A, after it has done its duty in that cylinder. Now, as the area of the larger cylinder is 4 times that of the smaller one, it follows that the steam expands to 4 times its volume in the larger cylinder, with a power corresponding to the diminution of force, and whilst the communication between the two cylinders is open, there is the same pressure in both cylinders, consequently the effective pressure in the larger cylinder is only on the three-fourths of its area, which it exceeds the smaller one.

As has been seen, the pressure of elastic fluids is inversely as the space they occupy; if we suppose these cylinders divided into, say six equal parts, 1, 2, 3, 4, 5, 6, it will sufficiently illustrate the comparative force of two cylinders.

For a constant quantity we have the capacity of the smaller cylinder, as 6 cubic feet, to be expanded into 24 cubic feet, and also fill the passages, say $\frac{6}{10}$ of a foot, between the cylinders. If the pistons be moved through one-sixth of their stroke to *a a*, the pressure would be as under:

IN SMALL CYLINDER.				IN LARGE CYLINDER.				
Full pres.		Empty space.		Space still filled.		Space filled.		Passages.		Steam expanded to fill.
c. ft.		c. ft.		c. ft.		c. ft.		c. ft.		c. ft.
6	—	0	=	0	+	0	+	·0	=	6· initial
6	—	1	=	5	+	4	+	·6	=	9·6 for *a a*
6	—	2	=	4	+	8	+	·6	=	12·6 for *b b*
6	—	3	=	3	+	12	+	·6	=	15·6 for *c c*
6	—	4	=	2	+	16	+	·6	=	18·6 for *d d*
6	—	5	=	1	+	20	+	·6	=	21·6 for *e e*
6	—	6	=	0	+	24	+	·0	=	24·6 for *f f*

Taking the force of steam as 40 lbs. per square inch, the pressures for the respective ordinates of expansion, in double and single cylinder engines, would then be inversely—

	Expand. space.		lbs.		Orig. space.		In dble. cylin. lbs.	Expanded space.	In single cylin. lbs.
Initial in first cylin.	6	:	40	::	6	:	40·	none	40·
Initial in second cyl.	6·6	:	40	::	6	:	36·36	between the pistons	none
First space of expan.	9·6	:	40	::	6	:	25·	ditto, or *a a*	26·26
Second ,,	12·6	:	40	::	6	:	19·04	ditto, or *b b*	20·
Third ,,	15·6	:	40	::	6	:	15·38	ditto, or *c c*	16·
Fourth ,,	18·6	:	40	::	6	:	12·36	ditto, or *d d*	13·33
Fifth ,,	21·6	:	40	::	6	:	11·11	ditto, or *e e*	11·42
Sixth ,,	24·6	:	40	::	6	:	9·75	ditto, or *f f*	10·

The mean pressure may be found by the rules already submitted. For the large cylinder by hyp. log. it will be

Exponent of expansion = 24·6 ÷ 6 = 4·1, whose log. = 1.411 × 36·36 × 6·6 ÷ 18·6 (spaces to fill) = 18·2 lbs., nearly as the mean pressure throughout the stroke on the large piston. On the smaller piston it would be 40 − 18·2 (the pressure on the larger piston) = 21·8 lbs., hence taking the value of the vacuum in the condenser as = to 12 lbs., for the power exerted we have the

Small cylinder area = 6 × 21·8 = 120·8
Large cylinder area = 24 × 18·3 = 436·8 } ÷ 24 = 35·23 lbs. mean pressure.
Condenser vacuum = 24 × 12·0 = 288

Total power . . = 845·6

Out of this 845·6 lbs. of accumulated power, 288 lbs., or one-third of the whole, is due to the vacuum in the condenser, and 557·6, or two-thirds, to the steam.

It may be instructive to compare the power given out in a single cylinder of the same capacity, and using the same quantity of steam. Thus, Nap. log. of 4·1 = 1·411 × 40 × 6 ÷ 18·6 = 17·67 lbs. as the mean pressure of expansion.

And as before—

Full pressure area	= 6 × 40	= 240·00	÷ 24 = 35·99 lbs. mean pressure.
Expended press. area	= 18·6 × 17·67	= 328·66	
Condenser vacuum	= 24·6 × 12·0	= 295·20	
Total power . . .		= 863·86	

Now 863·86 – 845·6 = 18·26 lbs., or 2·16 per cent. in favour of the power given out on one cylinder; but with this greater power there is also much greater irregularity of motion. For various classes of machinery now driven by steam such irregular motion would be highly detrimental, whilst the more uniform motion produced by the double-cylinder engine enables the principle of expansion to be more extensively applied to general purposes than by the single-cylinder engine.

There are other modifications of the double or combined cylinder engine, where the cylinders are placed on the top of each other, and differently arranged to provide the utmost economy; but the diagram conveys the idea of their action more clearly than if mechanically correct in the arrangement of the steam passages or position of the cylinders. They are a valuable class of engines.

GENERAL REFERENCE TABLES.

Table, No. 57, contains the average properties of unexpanded steam of different temperatures and in various definitions.

TABLE, No. 57.

EMPERATURE, PRESSURE, AND RELATIVE VOLUME OF STEAM FROM 212° TO 387·3° FAH. IN ENGLISH AND FRENCH MEASURES.

Pressure on a Square Inch, including the Pressure of the Atmosphere.		Elastic Force in		Temperature in Degrees of			Volume of Steam compared with the Volume of Water.	Power of 1 cub. ft. of water as steam in lbs. raised 1 ft. high.
		Inches of Mercury.	Metres of Mercury.	Fahrenheit.	Reaum.	Cent.		
bs.	kilog.	in.	metres.	deg.	deg.	deg.	lines.	lbs.
4·7	6·668	30·00	·762	212·0	80·0	100·0	1700	2083
5	6·80	30·60	·778	212·8	80·4	100·4	1669	2086
6	7·26	32·64	·829	216·3	81·9	102·4	1573	2097
7	7·71	34·68	·880	219·6	83·3	104·2	1488	2107
8	8·16	36·72	·932	222·7	84·7	105·9	1411	2117
9	8·62	38·76	·984	225·6	86·0	107·6	1343	2126
0	9·07	40·80	1·037	228·5	87·3	109·2	1281	2135
1	9·52	42·84	1·089	231·2	88·5	110·7	1225	2144
2	9·98	44·88	1·140	233·8	89·7	112·1	1174	2152
3	10·43	46·92	1·192	236·3	90·8	113·5	1127	2169
4	10·88	48·96	1·244	238·7	91·9	114·8	1084	2168
5	11·34	51·00	1·296	241·0	93·0	116·1	1044	2175
6	11·79	53·04	1·348	243·3	93·9	117·4	1007	2182
7	12·25	55·08	1·400	245·5	94·9	118·6	973	2189
8	12·70	57·12	1·452	247·6	95·8	119·8	941	2196
)	13·15	59·16	1·503	249·6	96·7	120·9	911	2202
)	13·61	61·21	1·555	251·6	97·6	122·0	883	2209
l	14·06	63·24	1·607	253·6	98·5	123·1	857	2215
!	14·51	65·28	1·659	255·5	99·3	124·2	833	2221
i	14·97	67·32	1·711	257·3	100·1	125·2	810	2226
	15·42	69·36	1·763	259·1	100·9	126·2	788	2232
	15·87	71·40	1·814	260·9	101·7	127·2	767	2238
	16·33	73·44	1·866	262·6	102·5	128·1	748	2243
	16·78	75·48	1·918	264·3	103·2	129·1	729	2248
	17·23	77·52	1·970	265·9	104·0	129·9	712	2253
	17·69	79·56	2·022	267·5	104·7	130·8	695	2259
	18·14	81·60	2·074	269·1	105·4	131·7	679	2264
	18·59	83·64	2·126	270·6	106·0	132·6	664	2268
	19·05	85·68	2·178	272·1	106·7	133·4	649	2273
	19·50	87·72	2·229	273·6	107·4	134·2	635	2278
	19·96	89·76	2·281	275·0	108·0	135·0	622	2282
	20·41	91·80	2·333	276·4	108·6	135·8	610	2287
	20·86	93·84	2·385	277·8	109·2	136·6	598	2291
	21·32	95·88	2·437	279·2	109·9	137·3	586	2296
	21·77	97·92	2·489	280·5	110·4	138·1	575	2300
	22·22	99·96	2·541	281·6	111·1	138·8	564	2304
	22·68	102·00	2·592	283·2	111·6	139·6	554	2308
	23·13	104·04	2·644	284·4	112·2	140·2	544	2312

Pressure on a Square Inch, including the Pressure of the Atmosphere.		Elastic Force in		Temperature in Degrees of			Volume of Steam compared with the Volume of Water,	Power of 1 cub. ft. of water as steam in lbs. raised 1 ft. high.
		Inches of Mercury.	Metres of Mercury.	Fahrenheit.	Reaum.	Cent.		
lbs.	kilog.	in.	metres.	deg.	deg.	deg.	lines.	lbs.
52	23·59	106·08	2·696	285·7	112·8	140·9	534	2316
53	24·04	108·12	2·748	286·9	113·3	141·6	525	2320
54	24·49	110·16	2·800	288·1	113·8	142·3	516	2324
55	24·95	112·20	2·852	289·3	114·4	142·9	508	2327
56	25·40	114·24	2·903	290·5	114·9	143·6	500	2331
57	25·85	116·28	2·955	291·7	115·4	144·3	492	2335
58	26·31	118·32	3·007	292·9	116·0	144·9	484	2339
59	26·76	120·36	3·059	294·2	116·5	145·7	477	2343
60	27·21	122·40	3·111	295·6	117·2	146·4	470	2347
61	27·67	124·44	3·163	296·9	117·7	147·2	463	2351
62	28·12	126·48	3·215	298·1	118·3	147·8	456	2355
63	28·57	128·52	3·266	299·2	118·8	148·4	449	2359
64	29·03	130·56	3·318	300·3	119·2	149·1	443	2362
65	29·48	132·60	3·370	301·3	119·7	149·6	437	2365
66	29·93	134·64	3·422	302·4	120·2	150·2	431	2369
67	30 39	136·68	3·474	303·4	120·6	150·8	425	2372
68	30·84	138·72	3·526	304·4	121·1	151·3	419	2375
69	31·29	140·76	3·577	305·4	121·5	151·9	414	2378
70	31·75	142·80	3·629	306·4	122·0	152·4	408	2382
71	32·20	144·84	3·681	307·4	122·4	153·0	403	2385
72	32·66	146·88	3·733	308·4	122·8	153·6	398	2388
73	33·11	148·92	3·785	309·3	123·2	154·1	393	2391
74	33·56	150·96	3·837	310·3	123·7	154·6	388	2394
75	34·02	153·02	3·889	311·2	124·1	155·1	383	2397
76	34·47	155·06	3·940	312·2	124·5	155·7	379	2400
77	34·93	157·10	3·992	313·1	124·9	156·2	374	2403
78	35·38	159·14	4·044	314·0	125·3	156·7	370	2405
79	35·83	161·18	4·096	314·9	125·7	157·2	366	2408
80	36.29	163·22	4·148	315·8	126·1	157·7	362	2411
81	36·74	165·26	4·199	316·7	126·5	158·2	358	2414
82	37·19	167·30	4·252	317·6	126·9	158·7	354	2417
83	37·65	169·34	4·303	318·4	127·3	159·1	350	2419
84	38·10	171·38	4·355	319·3	127·7	159·6	346	2422
85	38·55	173·42	4·407	320·1	128·0	160·1	342	2425
86	39.01	175·46	4·459	321·0	128·4	160·6	339	2427
87	39·46	177·50	4·511	321·8	128·8	161·0	335	2430
88	39 91	179·54	4·563	322·6	129·2	161·4	332	2432
89	40.37	181·58	4·615	323·5	129·6	161·9	328	2435
90	40·82	183·62	4·666	324·3	129·9	162·4	325	2438
91	41·27	185·66	4·718	325·1	130·3	162·8	322	2440
92	41·73	187·70	4·770	325·9	130·6	163·3	319	2443
93	42·18	189·74	4·822	326·7	131·0	163·7	316	2405
94	42·64	191·78	4·874	327·5	131·3	164·2	313	2448
95	43·09	193·82	4·926	328·2	131·6	164·8	310	2450

Pressure on a Square Inch, including the Pressure of the Atmosphere.		Elastic Force in		Temperature in Degrees of			Volume of Steam compared with the Volume of Water.	Power of 1 cub. ft of water as steam in lbs. raised 1 ft. high.
		Inches of Mercury.	Metres of Mercury.	Fahrenheit.	Reaum.	Cent.		
lbs.	kilog.	in.	metres.	deg	deg.	deg.	lines.	lbs.
96	43·54	195·86	4 977	329·0	132·0	165·0	307	2453
97	44.00	197·90	5·029	329·8	132·4	165·4	304	2455
98	44·45	199·92	5·081	330·5	132·7	165·8	301	2457
99	44·90	201·96	5·133	331·3	133·0	166·3	298	2460
100	45·36	204·01	5·185	332·0	133·3	166·7	295	2462
110	49·89	224·40	5·703	339·2	136·5	170·7	271	2486
120	54·43	244·82	6·222	345·8	139·5	174·3	251	2507
130	58·97	265·23	6·740	352·1	142·3	177·8	233	2527
140	63·50	285·61	7·259	357·9	144·8	181·1	218	2545
150	68·04	306·03	7·778	363·4	147.3	184·1	205	2561
160	72·57	326·42	8·296	368·7	149·6	187·1	193	2577
170	77·11	346·80	8·814	373·6	151·8	189·8	183	2593
180	81·65	367·25	9·333	378·4	153·9	192·4	174	2608
190	86·18	387·61	9·851	382·9	156·0	194·9	166	2622
200	90·72	408·04	10·370	387·3	157·9	197·4	158	2636
210	95·23	428·42	10·88	391·3	159·7	199·6	151	2650
220	99·77	448·82	11·39	395·5	161·2	201·9	145	2663
230	104·3	469·22	11·91	399·4	163·3	206·9	140	2675
240	108·8	489·62	12·43	403·1	164·9	206·1	134	2689

Table, No. 58, contains the specific quantity and power of a cubic foot of water evaporated per hour under various pressures.

The relative weight of steam to water is nearly as their relative volumes. Thus, in Table No. 57, the relative volume of steam of atmospheric pressure is given as 1700, therefore the weight of a cubic foot of steam is $\frac{1}{1700}$th part of a cubic foot of water, or 256·7 grains, as given in Table No. 58. For a cubic foot of water = 62·32 lbs. × 7000 grains troy each lb., so that 436,240 grains ÷ by 1700 = 256·7 grains; and for other pressures use the ratio of the volume for a divisor.

Inches of mercury × ·4919 = lb. avoirdupois, and lb. av. × 2·03294 = inches of mercury.

Table, No. 60, contains the Arithmetical Pressures, Means and Ratios of a Power of 1, expanded 24 times and at 24 different ordinates of any stroke, illustrated by Diagram, No. 50, and page 206.

TABLE, No. 58.

POWER OF STEAM FROM ONE CUBIC FOOT OF WATER GENERATED UNDER VARIOUS PRESSURES.

DESCRIPTION OF STEAM.					ITS MECHANICAL FORCE OR POWER.				IN A HIGH PRESSURE ENGINE.			
Temp.	Pressure in	Specific Gravity.			Power = to a		Or a Weight raised 1 Foot of	Or, in Horse Power of 33,000 lbs.	Taking the Horse Power as 30,000 lbs.			
		Spec. Grav. to Air = 1.	Weight of a Cubic Foot. in	in	Weight of	Raised to a Height of			TotalPower.	Atmospheric Resistance in		Available Power.
Fah.	lbs.	Ratio.	grs.troy	lbs. av.	lbs.	ft.	lbs.	H. P.	H. P.	lbs.	H. P.	H. P.
212	14·706	·477	256·7	·0366	2117·6	1700	60,000	1·818	2·000	60,000	2·000	—
212·8	15	·488	261·4	·0373	2160	1669	60,084	1·821	2·0028	58,904	1·963	·0384
220	17·5	·560	300·8	·0429	2520	1450	60,900	1·845	2·0300	51,175	1·706	·324
228·5	20	·655	340·5	·0486	2880	1281	61,488	1·863	2·0496	45,210	1·507	·542
234·2	22·5	·708	379·3	·0542	3240	1150	62,100	1·882	2·0700	40,587	1·353	·617
244·5	26·25	·814	436·2	·0627	3780	1000	63,000	1·909	2·100	35,293	1·176	·924
251·6	30	·922	494	·0757	4320	883	63,576	1·926	2·1192	31,164	1·039	1·080
264·9	37	1·131	605·9	·0865	5400	720	64,800	1·963	2·160	25,411	·847	1·313
269·1	40	1·199	642·5	·0918	5760	679	65,184	1·975	2·1728	23,964	·799	1·373
276·4	45	1·334	715·1	·1021	6480	610	65,880	1·996	2·1960	21,529	·717	1·479
283·2	50	1·469	787·4	·1125	7200	554	66,480	2·013	2·2160	19,552	·652	1·564
286·3	52·5	1·536	823·1	·1176	7560	530	66,766	2·034	2·2383	18,705	·623	1·613
295·6	60	1·736	930	·1328	8640	470	67,680	2·051	2·2560	17,254	·575	1·671
306·4	70	1·996	1069·2	·1527	10080	408	68,544	2·077	2·2848	14,400	·480	1·804
311·3	75	2·126	1139	·1627	10800	383	68,960	2·089	2·2986	13,517	·450	1·848
315·8	80	2·249	1205·1	·1721	11520	362	69,504	2·106	2·3168	12,776	·426	1·89
324·3	90	2·505	1342·3	·1917	12960	325	70,200	2·117	2·3400	11,470	·382	1·958
328·2	95	2·627	1407·2	·2010	13680	310	70,680	2·141	2·356	10,941	·364	1·992
332	100	2·760	1478·8	·2112	14400	295	70,800	2·145	2·3600	10,411	·347	2·018
[illegible]·2	105	2·877	1541·4	·2202	15120	283	71,316	2·161	2·3772	9,986	·333	2·044
[illegible]·2	110	3·005	1610·1	·2300	15840	271	71,544	2·168	2·3848	9,565	·318	2·066
[illegible]·5	114·7	3·120	1671·4	·2387	16517·6	261	71,851	2·177	2·3950	9,212	·307	2·088
[illegible]·8	120	3·257	1744·9	·2492	17280	250	72,000	2·182	2·4000	8,823	·294	2·106
352·1	130	3·494	1872·2	·2674	18720	233	72,696	2·203	2·4232	8,223	·274	2·149
352·4	135	3·619	1938·8	·2765	19440	225	73,224	2·219	2·4408	7,941	·264	2·176
357·9	140	3·733	2000·1	·2857	20160	218	73,250	2·220	2·4416	7,694	·256	2·185
263·4	150	3·969	2126	·3040	21600	205	73,600	2·230	2·4533	7,235	·241	2·212
368·7	160	4·241	2272·1	·3245	23040	192	73,728	2·234	2·4576	6,776	·226	2·231
371·1	165	4·354	2332·8	·3332	23760	187	74,052	2·244	2·4684	6,570	·219	2·249
373·6	170	4·474	2396·9	·3369	24480	182	74,256	2·250	2·4752	6,423	·214	2·261
378·4	180	4·771	2521·6	·3602	25920	173	74,736	2·264	2·4912	6,105	·203	2·288
382·9	190	4·935	2643·9	·3777	27360	165	75,240	2·280	2·5080	5,823	·194	2·314
385·1	195	5·058	2709·6	·3870	28080	161	75,348	2·283	2·5116	5,682	·189	2·322
387·3	200	5·186	2778·6	·3968	28800	157	75,569	2·290	2·5189	5,541	·184	2·334
389·6	210	5·537	2906·6	·4152	30240	150	75,600	2·291	2·5200	5,294	·176	2·344
393	220	5·655	3029·5	·4328	31680	144	76,032	2·304	2·5344	5,082	·169	2·365
395	225	5·776	3093·9	·4420	32400	141	76,140	2·307	2·5380	4,960	·165	2·373
402	240	6·126	3280	·4685	34560	133	76,608	2·321	2·5536	4,694	·156	2·397
414	300	7·366	3930·1	·5614	43200	111	79,920	2·421	2·664	3,751	·126	2·539
456	450	10·179	5453	·779	62800	80	83,733	2·537	2·7911	2,823	·094	2·697
478	600	13·574	7270·8	1·0387	86400	60	86,400	2·617	2·8800	2,117	·070	2·810

Table, No. 59.

NAPIERIAN OR HYPERBOLIC LOGARITHMS.—Page 205.

Num.	Nap. Log.	Num.	Nap. Log.	Num.	Nap. Log.	Num.	Nap. Log.	Num.	Nap. Log.
1·05	·049	3·05	1·115	5·05	1·619	7·05	1·953	9·05	2·203
1·1	·095	3·1	1·131	5·1	1·629	7·1	1·960	9·1	2·208
1·15	·140	3·15	1·147	5·15	1·639	7·15	1·967	9·15	2·214
1·2	182	3·2	1·163	5·2	1·649	7·2	1·974	9·2	2·219
1·25	223	3·25	1·179	5·25	1·658	7·25	1·981	9·25	2·225
1·3	262	3·3	1·194	5·3	1·668	7·3	1·988	9·3	2·230
1·35	300	3·35	1·209	5·35	1·677	7·35	1·995	9·35	2·235
1·4	336	3·4	1·224	5·4	1·686	7·4	2·001	9·4	2·241
1·45	372	3·45	1·238	5·45	1·696	7·45	2·008	9·45	2·246
1·5	405	3·5	1·253	6·5	1·705	7·5	2·015	9·5	2·251
1·55	438	3·55	1·267	5·55	1·714	7·55	2·022	9·55	2·257
1·6	470	3·6	1·281	5·6	1·723	7·6	2·028	9·6	2·262
1·65	500	3·65	1·295	5·65	1·732	7·65	2·035	9·65	2·267
1·7	531	3·7	1·308	5·7	1·740	7·7	2·041	9·7	2·272
1·75	560	3·75	1·322	5·75	1·749	7·75	2·048	9·75	2·277
1·8	588	3·8	1·335	5·8	1·758	7·8	2·054	9·8	2·282
1·85	615	3·85	1·348	5·85	1·766	7·85	2·061	9·85	2·287
1·9	642	3·9	1·361	5·9	1·775	7·9	2·067	9·9	2·293
1·95	668	3·95	1·374	5·95	1·783	7·95	2·073	9·95	2·298
2·0	693	4·0	1·386	6·0	1·792	8·0	2·079	10·	2·303
2·05	718	4·05	1·399	6·05	1·800	8·05	2·086	15·	2·708
2·1	742	4·1	1·411	6·1	1·808	8·1	2·092	20·	2·996
2·15	765	4·15	1·423	6·15	1·816	8·15	2·098	25·	3·219
2·2	788	4·2	1·435	6·2	1·824	8·2	2·104	30·	3·401
2·25	811	4·25	1·447	6·25	1·833	8·25	2·110	35·	3·555
2·3	833	4·3	1·459	6·3	1·841	8·3	2·116	40·	3·689
2·35	854	4·35	1·470	6·35	1·848	8·35	2·122	45·	3·807
2·4	875	4·4	1·482	6·4	1·856	8·4	2·128	50·	3·912
2·45	896	4·45	1·493	6·45	1·864	8·45	2·134	55·	4·007
2·5	916	4·5	1·504	6·5	1·872	8·5	2·140	60·	4·094
2·55	936	4·55	1·515	6·55	1·879	8·55	2·146	65·	4·174
2·6	956	4·6	1·526	6·6	1·887	8·6	2·152	70·	4·248
2·65	975	4·65	1·537	6·65	1·895	8·65	2·158	75·	4·317
2·7	993	4·7	1·548	6 7	1·902	8·7	2·163	80·	4·382
2·75	1·012	4·75	1·558	6·75	1·910	8·75	2·169	85·	4·443
2·8	1·030	4·8	1·569	6·8	1·917	8·8	2·175	90·	4·500
2·85	1·047	4·85	1·579	6·85	1·924	8·85	2·180	99·	4·554
2·9	1·065	4·9	1·589	6·9	1·931	8·9	2·186	100·	4·605
2·95	1·082	4·95	1·599	6·95	1·939	8·95	2·192	1000·	6·908
3.0	1·099	5·0	1·609	7·0	1.946	9·0	2·197	10,000·	9·210

Note.—Hyperbolic logarithms express the areas of the irregular spaces or divisions of the rectangular hyperbola whose congregate and transverse axes are equal, and whose ordinates decrease in geometrical progression. Common logarithms multiplied by 2·30258 give hyperbolic or Napierian logarithms.

Table, No. 60.—Relative Pressures of Steam Expanded to Twenty Four Times —Page 206.

RELATIVE LENGTHS OF ORDINATES WHEN STEAM IS CUT OFF AS FIG. No. 50.

l pressure =	1	2	3	4	5	6	7	8	9	10	11	12
l to expan. =	1/24	1/12	1/8	1/6	5/24	1/4	7/24	1/3	3/8	5/12	13/24	1/2
pand· to full=	23/24	11/12	7/8	5/6	19/24	3/4	17/24	2/3	5/8	7/12	11/24	1/2
1	1·	1·	1·	1·	1·	1·	1·	1·	1·	1·	1·	1·
2	·5	1·	1·	1·	1·	1·	1·	1·	1·	1·	1·	1
3	·333	·666	1·	1·	1·	1·	1·	1·	1·	1·	1·	1·
4	·25	·5	·75	1·	1·	1·	1·	1·	1·	1·	1·	1·
5	·2	·4	·6	·8	1·	1·	1·	1·	1·	1·	1·	1·
6	·166	·333	·5	·666	·833	1·	1·	1·	1·	1·	1·	1·
7	·143	·285	·428	·571	·714	·857	1·	1·	1·	1·	1·	1·
8	·125	·25	·375	·5	·625	·75	·875	1·	1·	1·	1·	1·
9	·111	·222	·333	·444	·555	·666	·777	·888	1·	1·	1·	1·
10	·10	·2	·3	·4	·5	·6	·700	·800	·900	1·	1·	1.
11	·0909	·1818	·2727	·363	·454	·545	·636	·727	·818	·909	1·	1·
12	·0833	·166	·25	·333	·416	·5	·583	·666	·750	·833	·916	1·
13	·0769	·154	·23	·307	·385	·461	·538	·615	·692	·769	·846	·923
14	·0714	·143	·214	·285	·357	·428	·500	·571	·642	·714	·785	·857
15	·0666	·133	·2	·266	·333	·40	·4666	·533	·600	·666	·738	·800
16	·0625	·125	·187	·25	·312	·375	·437	·500	·5625	·625	·687	·750
17	·0588	·117	·176	·235	·294	·353	·4116	·472	·5294	·588	·647	·706
18	·0555	·111	·166	·222	·277	·333	·3882	·444	·500	·555	·611	·666
19	·0526	·105	·157	·21	·263	·315	·3682	·421	·473	·526	·578	·630
20	·050	·1	·150	·20	·25	·3	·350	·400	·450	·500	·550	·600
21	·0476	·095	·142	·19	·238	·285	·3333	·380	·4285	·476	·523	·571
22	·0454	·0909	·136	·181	·227	·272	·3178	·363	·4090	·454	·500	·545
23	·0434	·087	·13	·173	·217	·26	·3038	·347	·3913	·436	·477	·520
24	·0416	·0833	·125	·166	·208	·25	·2916	·333	·3750	·416	·458	·500
xpan. power =	2·774	4·547	5·821	6.762	7.458	7·950	8·277	8·460	8·520	8·467	8·316	8·068
tal power - =	3·774	6·547	8·821	10·762	12·458	13·950	15·277	16·460	17·520	18 467	19·316	20·068
t.to full as 1· =	3·774	3·273	1·974	1·69	1·491	1·325	1·182	1·057	·946	·851	·756	·672
eans of exp.pr=	·1206	·2067	·277	·338	·392	·441	·486	·528	·568	·608	·639	·072
ns. of total pr.=	·157	·272	·367	·448	·518	·581	·636	·685	·730	·771	·804	·836

l pressure =	13	14	15	16	17	18	19	20	21	22	23	24
l to expan. =	13/24	7/12	5/8	2/3	17/24	9/19	19/24	5/6	5/8	11/12	23/24	24
pand· to full=	11/24	5/12	3/8	1/3	7/24	3/12	5/24	1/6	3/8	1/12	1/24	0
1	1·	1·	1·	1·	1·	1·	1·	1·	1·	1·	1·	1·
2	1·	1·	1·	1·	1·	1·	1·	1·	1·	1·	1·	1·
3	1	1·	1·	1·	1·	1·	1·	1·	1·	1	1·	1·
4	1·	1·	1·	1·	1·	1·	1·	1	1·	1·	1·	1·
5	1·	1·	1·	1·	1·	1·	1·	1·	1·	1·	1·	1·
6	1·	1·	1	1·	1·	1·	1·	1·	1·	1·	1·	1·
7	1·	1·	1·	1·	1	1·	1·	1·	1·	1·	1·	1·
8	1·	1·	1·	1·	1	1·	1·	1·	1·	1·	1·	1·
9	1·	1·	1·	1·	1·	1·	1·	1·	1·	1·	1·	1·
10	1·	1·	1·	1·	1·	1·	1·	1·	1·	1·	1·	1·
11	1·	1·	1·	1·	1·	1·	1·	1·	1·	1·	1·	1·
12	1·	1·	1·	1·	1·	1·	1·	1·	1·	1·	1·	1·
13	1·	1·	1·	1·	1·	1·	1·	1·	1·	1·	1	1·
14	·928	1·	1·	1·	1·	1·	1·	1·	1·	1·	1	1·
15	·866	·933	1·	1·	1·	1·	1·	1·	1·	1·	1·	1·
16	·812	·875	·937	1·	1·	1·	1·	1·	1·	1·	1·	1·
17	·764	·823	·882	·941	1·	1·	1·	1·	1·	1·	1·	1·
18	·722	·777	·838	·888	·944	1·	1·	1·	1·	1	1·	1·
19	·684	·736	·790	·842	·894	·947	1·	1·	1·	1·	1·	1·
20	·650	·700	·750	·800	·850	·900	·95	1·	1·	1·	1·	1·
21	·619	·666	·714	·761	·809	·857	·904	·952	1·	1·	1·	1·
22	·590	·635	·681	·727	·772	·818	·863	·909	·954	1·	1·	1·
23	·565	·607	·652	·695	·739	·782	·826	·869	913	·956	1·	1·
24	·541	·583	·625	·666	·708	.750	·791	·833	·875	·916	·958	1·0
xpan. power =	7·741	7·335	6·870	6 320	5·716	5·054	4·334	3·563	2·742	1·872	·958	·00
tal power - =	20·741	21·335	21·870	22 320	22·716	23·054	23·334	23·563	23·742	23 872	23·958	24·
t.to full as 1· =	·595	·524	·458	·395	·336	·281	·228	·178	·130	·085	·041	·00
eans of exp.pr=	·704	·733	763	·790	·816	·842	·866	·895	·914	·936	·958	·00
ns. of total pr.=	·864	·889	·911	·930	·946	·960	·972	·981	·989	·994	·998	1·0

, The Means of full pressure are each taken as a power = 1; and the Exp. and total Means are each their relative proportion to the initial pressure as = 1.

Application of Steam Tables.

To find the power of water as steam (Tables 57, 58).

1st. Multiply the pressure in lbs. per square inch by the relative volume of steam to water, and divide by twelve for the lbs. raised one foot by one cubic inch of water as steam.

2nd. Multiply the pressure in lbs. per square foot by the relative volume of steam to water for the lbs. raised one foot by one cubic foot of water as steam.

Ex.—Required the power of water as steam of atmospheric pressure, or 14·706 lbs. per square inch, and its relative volume = 1700?

1st. 14·706 × 1700 ÷ 12 = 2083 lbs. raised 1 foot by 1 cubic inch of water.

2nd. 14·706 × 144 sq. in. × 1700 = 3,600,028 lbs. raised 1 foot by 1 cubic foot of water.

The horse-power dynam. is variously estimated from 22,000 to 44,000 lbs. raised one foot, and Watt adopted 33,000 lbs.; but the advantage of a more simple unit has many advocates. Taking the power of a cubic foot of water as steam of atmospheric pressure, as 3,600,028 lbs. per hour, it gives 60,000 lbs. per minute, or say two horse-power of 30,000 lbs. This convenient multiple of three, founded on the natural law of atmospheric pressure, is adopted in Table 58, to promote the desired simplicity.

The usual 33,000 lb. dynam. is also a multiple of three; hence one-tenth the number of these dynams. *added to them* gives the number of 30,000 lb. dynams., and one-eleventh of the 30,000 lb. dynams. *deducted* from themselves leaves the number of 33,000 lb. values from the same amount of power in lbs. raised one foot.

Ex.—If steam of 45 lbs. pressure from 1 cubic foot of water raises 65,880 lbs. 1 foot high per minute (Table 59), required the horse power thereof?

1st. 65880 ÷ 30000 = 2·196 h. p.—$\frac{1}{11}$th = 1·996 h.p. of 33,000 lbs. value.
2nd. 65880 ÷ 33000 = 1·996 h. p. + $\frac{1}{10}$th = 2·196 h. p. of 30,000 lbs. value.

Power of Expanded Steam, Tables 58, 59.

To find the power of any ordinate, or mean expansion, or mean total power, multiply the respective tabular number by the initial pressure in pounds per square inch.

For the total power of a boiler, multiply the given evaporation in cubic feet per hour by the power in lbs., or in horse-power due to the given temperature or pressure in Table 59; and for the gain by expansion add the product of this power multiplied by the *Ratio* of the given expansion in Table 58.

For the available power of a high-pressure boiler or engine, from the total gross power as last found, deduct the atmospheric resistance in Table 59, multiplied by the evaporation per cubic foot per hour, and this product also multiplied by the *relative time* of expansive to full pressure action.

Ex.—Required the length of the 20th ordinate of expansion when the steam of 100 lbs. pressure is cut off at a quarter of its stroke?

Opposite the 20th ordinate in the Table, and under 4, the ratio of e-d pansion, is ·30, which being multiplied by the pressure 100 = 30 lbs. the pressure required.

Ex.—Required the total and available horse-power of a high-pressure boiler evaporating 100 cubic feet of water per hour, under a pressure of 100 lbs. per square inch? Also, when working an engine three-fourths expansively?

1st.—Total Power.

100 lbs. pres. Table 59 = 2·36 h. p. × 100 c. f. evap. = 236·00 h. p.
¼ full pres. Table 58 = 1·32 ratio × 236·00 = 311·52 h. p.

Total power = 547·52 h. p.

2nd.—Atmospheric Resistance.

At. res. of 100 lbs. pres. = ·347 h. p. × 100 evap. = 34·7 h. p. to full pressure, and 34·7 h. p. × 4 ratio of exp. = 138·8 h. p. of atm. res. to overcome, when the steam is expanded 4 times.

3rd.—Available Power.

Full press. = 236·00 h. p.—atm. res. of 34·7 h. p. = 191·30 h. p., and exp. 4 times = 547·52 h. p.—atm. res. of 138·8 h. p. = 408·72 h. p.

available power in a cylinder, where no loss arises in transmitting it there from the boiler.

SECTION III.

OUTLINE OF STEAM HISTORY.

CHAPTER I.

ANCIENT STEAM AND HOT AIR ENGINES.

The genealogy of steam, or hot air power, like that of heraldry, or science, or mechanics, or manufactures, passes into the romance of antiquity, and is besides involved in the secrecy of idolatrous worship, which has left only scanty means to trace it.

These means are historical allusions, but chiefly a philosophical treatise on the "Inventions of the Ancients," by Hero, of Alexandria, a pupil of Ctesibus, whose time is variously estimated as from 225 to 150 B. C.

Historically, however, since Hero recorded the existence of the steam-engine in an existing language, no retrogression marks its onward progress. An outline, therefore, of its history will more pleasingly convey rudimentary instruction on the application of steam power, than could be done by abstract reasoning. By this plan there is also the advantage of bringing into converse, as it were, the inventive ideas of past and present steam-engine improvers; for Boyle well remarked, that failures are as instructive as successes. The practice of seeking to enhance modern science by disparaging that of past ages is too often done, and we regret to find one so eminent as Dr. Lardner attempting to show that the ancients were ignorant of steam, because they described it as "air produced by heat from water."

As we have shown, steam is still treated as air in its elastic properties; and if these properties are described and acted upon, it is evidence of knowledge; for the description of any new discovery is necessarily comparative until a name is adopted.

Following the course usually adopted in giving practical forms to the descriptions of inventors, such as those of the Marquis of Worcester and others, two of Hero's altar engines will be shown as cranes, with a view of usefully illustrating the romance of steam and hot air engines.

To make these more clear, Homer's ships, which "plow with reason up the deeps," and Plato's reference to steam, will be first noticed.

Homer, 927 B. C.—It is uncertain how long steam power may have been employed; but in cooking it would early display its force, and lead ingenious minds to apply it otherwise. When the word "steam" was generally used for the vapour of water is not known; but Homer speaks of "steam" from roasting meat, as it is yet spoken of; and his description of the Phæacian ships is an instance of great power being poetically, if not really, existent.

In Ogilby's edition of his Odyssey, dated 1699, Homer makes the Phæacian Prince thus address Ulysses the Greek:—

" Now, Sir, be pleased you would yourself declare,
Where you were born and what your Parents are,
And your Aboads: that so we may instruct
Our Ship, you to your Country to conduct;
We use nor Helm nor Helms-man. Our tall ships
Have Souls, and plow with Reason up the deeps.
All Cities, Countries know, and where they list,
Through Billows glide veiled in obscuring Mist;
Nor fear they Rocks, nor Dangers on the way,
But once I heard my sire, Nausithous, say,
Neptune enraged, because we do transport
So many people safe from Port to Port,
Returning will our vessel sink." * * *

This is a glowing description of navigation, conceived and described about 2800 years ago, if not partly realized by some potent agent whose powers seemed illimitable to Homer. In various other passages, when describing Grecian ships, oars only are referred to, as in Ulysses' command to avoid a rock :—

> " Sit on your Banks with pliant Oars to sweep,
> All as one man, the surface of the deep ;
> But Helmsman thy care the vessel must protect."

Paddle-wheel boats moved by manual, or horse, or other power, and oars, are the only ancient propellers now known besides sails.

If, then, those " renowned Phæacians," or ancient Egyptians, employed neither horse, nor steam, nor other potent motive agent to propel their ships, then Homer conceived and clothed with brilliant language a Great Idea, all but literally translated by recent Navigation.

From the well-known science of the Egyptians; from Homer's frequent reference to "Hecatombs of Cattell," sacrificed to propitiate the gods, accompanied by wood, fire, and water to the altar, and completed by LIBATIONS of wine poured on the sacrifice, as

> " On burning Altars a Libation due,"

we can scarcely doubt but that they were well acquainted with steam power as used in religious services ; and as Homer's assertion to Ulysses,

> " Since at Contrivements we are Skilful both
> For dex'trous Sleights, 'mongst Mortals thine's the prize,"

is attested by their existing monuments, it would be easy for such "skilful contrivers" to convert a "wine or water-raising engine" into a stone-raising one useful in the arts.

Plato, 390 B. C.—The prevailing darkness regarding the scientific and practical knowledge of the ancients is in a great measure due to the philosophers of those days, such as Plato, considering it derogatory to explain science to the uninitiated, or record the inventions of the "vulgar," however meritorious, beyond a passing allusion to them in other subjects.

Plato describes steam as water melted into air by heat, which could be compressed into water again—a very correct description of the generation and condensation of steam, although that word is not used.

He also makes Timæus speak of ingenious inventions in the mechanical arts; and from Plato's particular notice of steam power, it is evident that it was then a familiar object to learned and ingenious men, and may have been equally so in Homer's time. Neither can it be doubted that Aristotle, one of Plato's disciples, who died 322 B.C., Euclid, the mathematician, who flourished 300 B.C., Archimedes, the great geometrician and mechanician, who was basely slain 212 B.C., would be all conversant with steam and the steam mechanism of their days.

More particularly in the noble defence of Syracuse against the Romans is Archimedes believed to have employed steam in some of his defensive engines, whilst with his burning-lenses he attacked the invaders, and drew the attention of the world to the resources of mechanical science.

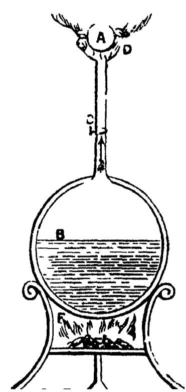
Hero, 150 B.C.—About this time, if not before, Hero of Alexandria wrote his able treatise on the "Inventions of the Ancients" of his day, which has associated his name with the invention of the steam-engine, although it appears to have been known some thousand years before his time. Hero states that some of the seventy-eight inventions he describes were his own, but does not specify which they are.

Like other sources of information, extending beyond the burning of the Alexandrian Library of 400,000 volumes by the Saracens under Omar, 640, A.D., steam, in all probability, also lost its records. Hero's treatise was written before this dire event, but policy would guide his selections from the records of former inventors, which he professedly gives.

In a commendable spirit of justice, Professor Woodcroft, of University College, London, and Professor Greenwood, of Owen College, Manchester, have jointly published a carefully revised edition of Hero's treatise on Pneumatics, which describes and illustrates seventy-eight "Ancient Inventions."*

Many of them are very ingenious, and display a knowledge of the properties of steam, air, and water. Amongst the number are a syphon, a fire-engine pump, a water-clock, steam-engines, altar-libation engines, singing-birds, and other devices, ending in an automaton drinking water after a knife had passed through its neck. They would well repay a careful examination†.

Fig. No. 52.



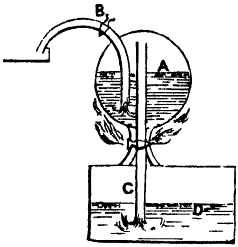
Ancient Steam-Engine.

Hero's 45th invention, Fig. No. 52, illustrates the force of steam in raising a weight A out of its seat in D, as it passes up the pipe C from the boiler B, in which it is generated by the fire F, which would also equally move a piston in a cylinder. This is still occasionally a lecture experiment; and the locomotive ball-valve is similar in its construction and action, by being raised from its seat by the water pumped into the boiler.

* Taylor and Walton, London.

† Hero also wrote four other treatises still extant, on "Missiles," on "Automata," on the "Dioptra" or spying tube, and on "Lifting heavy Bodies." A translation of the last would be a useful addition to Woodcroft's translation of the "Pneumatical Treatise," since there is no work existing on the every-day mechanism of the Antediluvians, or of the immediate descendants of Noah, acquainted with mechanism in use both before and after the flood.

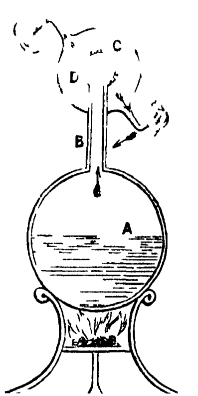
FIG. No. 53.



Ancient Hot Air Engine.

Hero's 47th invention, Fig. No. 53, is designed for the heat of the sun to expand the water in A, and by compressing the air on its surface jointly with the vapour formed, to force the contents in A up the pipe B. When A is cooled, the water in D would rise to fill the partial vacuum in A, and be emptied as before. By substituting a fire below A instead of the sun above it, we have a simple water-raising engine on De Caus's plan, but wanting the separate cylinders to make it either as complete or economical as the idolatrous engine, Fig. 55.

FIG. No 54..



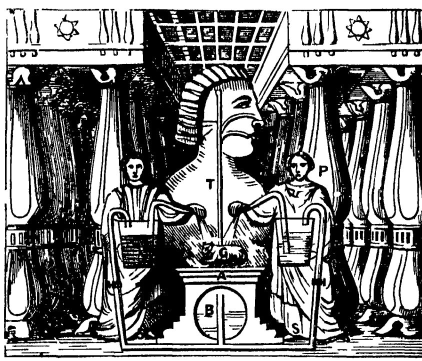
Ancient Rotatory Engine.

Hero's 50th invention, Fig. No. 54, is a simple yet complete rotatory steam-engine, capable of giving motion to machinery. The steam generated in A passes up the hollow frame B into the globe C, freely suspended on the point of B and on an opposite centre. The steam then issues at an orifice on one side only of each arm E F, against the air, whose resistance causes these arms to recede in an opposite direction and produce rotation of the globe C. If the steam had issued at both sides of the arms the resistances would have balanced each other without obtaining rotation, similarly to two persons of equal power opposing each other in opening a gate. By a pinion D, or pulley on the solid centre of the globe, motion could be communicated to machinery; and a modified engine of this class was recently employed in the printing establishment of the Messrs. Chambers of Edinburgh.*

* Before noticing the altar-engines, it may be interesting to state, that the properties of the atmosphere and a vacuum are discussed by Hero as

Altar-Engines.—Hero's description of these engines shows a clear knowledge how to apply the powers of steam or hot air to raise fluids. His 11th and 60th inventions, entitled "Libations at an Altar by Fire," and "Libations poured on an Altar, and a Serpent made to hiss, by Fire," display both scientific and practical skill. For on a large scale both libation-engines would be quite capable of exerting immense lifting power. One example will therefore be given as both morally and practically instructive on this point.

FIG. No. 55.



Double-acting Idolatrous Engine.

"I am all that has been, is, or will be, and no mortal has ever lifted my veil."—ISUS.

Let Fig. No. 55 represent Isus in his splendid temple with

they still are; that various figures illustrate the motive power between water and air-pressure; that Figs. 9, 49, and 54 show the power of compressed air; Fig. 27 an effective fire-extinguishing engine with two bronze cylinders, "bored in a lathe to fit pistons," and each piston connected to one end of a beam vibrating on its centre, as in modern engines; Figs. 11, 37, 38, 60, and 70, the power of hot air, or hot air with steam; Fig. 57, a syringe; Figs. 4, 33, 68, and 78 the screw-press, rack and pinion, bevel-gear, pulleys, and counter-weights; Figs. 74 and 75, cylindrical boilers with inner concentric hot air chambers or fire-the altar A*, sacrifice C, and the attendant altar guardians. Part of it is sectional, to show the secret engine clearly. B, the boiler from which the steam passes by the pipes S S into the wine cylinders to force their contents out by the pipes along the priest's arms, similar to Porta's, Worcester's, Morland's, Papin's, and Savary's and other similar water-raising engines. The wine pipes terminate in cups held by the priests, and a third steam-pipe, T, passes from the boiler to the idol's head, with branches to the mouth, or nose, or both. With convenient stop-cocks, and all concealed from view, this mechanism gave great power of deception.

Suppose, for instance, that the priestly exhortations were ended, and the worshippers expected the public sanction of the idol, hot air or steam admitted to the head would give the oracular response on any concealed musical or other mechanism there, whilst the steam would escape like breathing. In like manner with the sacrifice, steam or hot air admitted to the wine cylinders would cause it to flow out into the cups as if miraculously obtained. Since it better accounts for

places, (in which a fire-pan and grate could be let down, as in Moses' altar of burnt offerings,) and tubes for admitting air, for blowing the fire by hot air, for blowing a trumpet, and for whistling like a blackbird ; Fig. 76, an organ-blowing cylinder, with slide valves to each pipe, worked by a bell crank motion similar to the rocking shaft valve motion of locomotives, or Ericcson's caloric engine; and Fig. 77, a wind-mill working an organ-blowing cylinder. In the most elaborate of these designs, hot-air power is a leading feature, aided by steam to increase its effect.

* In the British Museum, Egyp. Gal., No. 135, is a small altar of libations, with a central tank (or boiler like Brindley's stone ones), and in the bottom are three holes, as if for pipes, arranged after Hero's design. In the Egypt Room, cases 24-5, is a libation vase with a large strap-like oval hole through it, and which divides it at that part into two separate vessels, but forming one vessel only at the top and bottom. This vase could be easily bound to any person or object, and its tubular orifice convey hot air or steam into it, whilst another similar tube might lead from its top—now broken off—to a cup in the priest's hand.

various historic records of scenes at idolatrous worship unaccountable to the witnesses, we have merely altered Hero's original "serpent's head hissing" for a man's head, as a statue, on which the heat of an eastern sun would generate steam of available force from any water concealed in it.*

Air would also produce similar effects when heated. By admitting it at one opening, and its expansion by heat shutting that entrance and opening another for escape, the heat of the sun would give sufficient power to emit sounds.

Philostratus states that sounds proceeded from Memnon like a stringed instrument, when the sun shone. Pausanius compares them to snapping the strings of a harp, and Strabo mentions his having heard similar sounds. Thus:

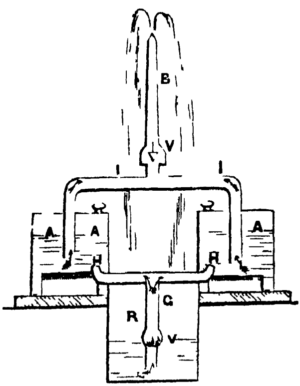
"Memnon's broken image sounding,
Tuneful 'midst desolation still."

Closed from the air, a little water confined in any exposed part of this celebrated idol would produce these sounds again and again, "when the sun shone." As such water would be literally in the position sought by some modern steam engineers, viz., to use the same water over and over again without loss, it would be a question of time how long water entirely excluded from the air would retain its usual properties of generating steam to produce these sounds, and at what temperature it would be produced.

De Caus's Sun Fountains, 1612.—The recorded movements of idols when the sun rose, and of the sounds proceeding from them, led the mechanics of the 17th century to imitate them by various ingenious arrangements of mechanical music. Amongst these was De Caus; and as showing the power of the sun on confined water, we give in this place two of his illustrations of ancient sun fountains, which may be otherwise interesting in these days of Crystal Palace fountains.

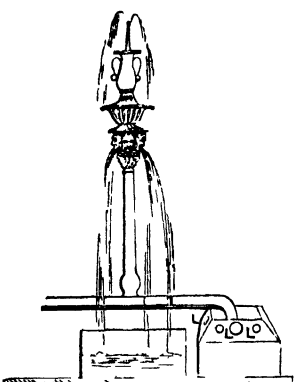
* Serpents were formerly venerated as idols.

FIG. No. 56.



Sun Fountain.

FIG. No. 57.

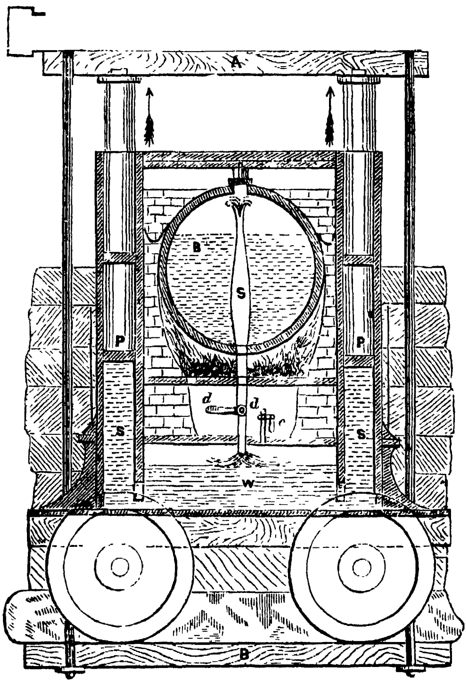


Lensed Sun Fountain.

Fig. No. 56 is a sectional view of two copper vessels (four were used) A A, filled with water at H H by atmospheric pressure from the well R. The heat of the sun expands the water in A A and forces it up the pipes I B about 5 or 6 feet. To increase the effect of the sun, "burning lenses," L L L, Fig. 57, were introduced, which raised the water much higher than before. The acting force is steam and air compressed in A A until their power exceeds that of the atmosphere acting on the water in R. With a fire instead of the sun, these would have been useful water-raising engines.

There exists, therefore, no good grounds to discredit the testimony of those who describe scenes often deemed fabulous, since our own "wizards" prove how readily the eye fails to detect artifices confessedly practised. Neither need it excite much surprise that nations had faith in a mythology at once sublime and awe-inspiring, and commanding the services of such clever priests and skilful mechanicians. For a good-sized engine was not only equal to gently pouring out wine, but might in one instant be made to eject the steam or water amongst or against any refractory worshippers, as is supposed was done by Archimedes to defend Syracuse.

FIG. No. 58.



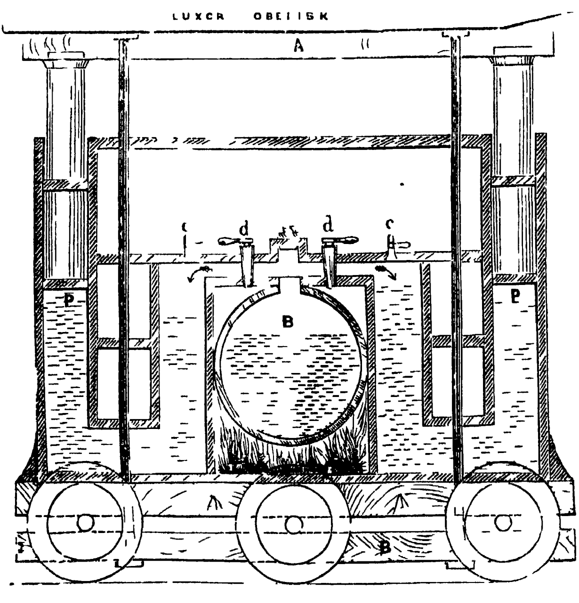
Single-acting Altar-Engine as a Crane.

Altar-Engines as Cranes.—Fig. No. 58 is a crane nearly identical in its form to Hero's 11th invention (which is a water-raising engine), but mounted on wheels for conveying materials from place to place. B the boiler, S the steam-pipe, W the water cistern, and S S the water elevation pipes. This is the altar hot air engine as shown by Hero. Now if we place a piston P in each tube S, and connect them together at the top by a platform A, from which another platform D is suspended, we have evidently a crane of great power and simplicity. For as air or steam admitted into the cistern forces the water up the pipes, so would any weight be lifted, within the limit of the crane power.

By opening the small cock *c*, weights could also be lowered by allowing the force to escape more or less rapidly, as required; in short, raise or lower weight with as much delicacy as is now done by any crane.

On the lowest platform a block or load could be readily placed from the ground, then raised one lift of the crane and blocked up for another lift, and so on until the required height was gained.

FIG. No. 59.



Double-acting Altar-Engine as a Crane.

Fig. 59 is a six-wheeled steam-crane on the plan of the wine libation engine Fig. 52, but with the steam-pipes from the top of the boiler, as they are not required to be concealed as in the altar-engine. The same letters apply as in Fig. 55. By this means still greater delicacy in raising blocks to any angle is obtained, by admitting steam to or from each separate syphon-shaped cylinder as required. With such cranes, the most ponderous monolinths, even the great sphynx itself, would be readily handled or removed.*

The destruction of Assyrian, Babylonian, Chaldean, and Egyptian power also annihilated their acquired knowledge and mechanism—a great loss to mankind.

The use of steam for religious and other professional purposes appears to have made its power a secret known only to the initiated, until the republication of Hero's treatise, in 1547, set in motion that mental power which step by step has made

* These cranes were engraved before seeing the sculptured outline of the 4 and 6-wheeled besieging engines of the Assyrians in the Nimroud Gallery of the British Museum, which embody a similar idea of power to work the highly-inclined battering or rather excavating arms, and of portability by wheels. Since such engines were employed to destroy edifices, by a slight modification they could also aid in erecting them, although it is the usual opinion that inclined planes, rollers, and man-power were the chief lifting resources of the ancients. This opinion is, however, scarcely consistent with their known scientific and practical resources, as exemplified by modern researches.

For special occasions, as in Mr. Layard's case, inclined planes or other expedients might be adopted, and from their contrast to the ordinary means be similarly delineated, yet as little represent the mechanica resources of the ancients as those employed in removing the Nimroud sculptures did those of Great Britain.

The efforts of commentators to explain down to their own ideal of ancient knowledge the plainest references to skilled productions by Moses, Homer, and others, ill accord with the results of discovery; and —space permitting—on the article on wheels a few examples of this class will be noticed, in support of the literal accuracy of the texts called in question, and of the mechanical skill of past ages.

the steam-engine what it is, and which is now experimenting with hot air on a large scale in America.

Anthemius, 530.—In revenge for having been baffled in a wordy dispute by Zeno the orator, this architect of Justinian conveyed steam by elastic pipes below the floor of Zeno's house, and so alarmed the orator that he yielded to a rival who shook his house and the "earth as with the trident of Neptune." It is thus clear that Zeno had no knowledge of steam power, so familiar to his professional opponent.

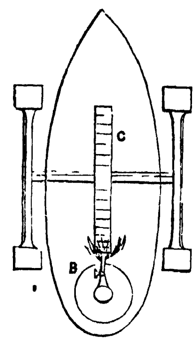
Gerbert, 1125.—This learned priest appears to have applied one of Hero's plans to an organ at Rheims, in which the air, escaping by the force of heated water, produced musical tones in combination with water.

Alberti, 1412.—The knowledge of the extreme force of steam again appears professionally by Alberti comparing it, when generated from water in the cavities of limestones, as bursting them with great noise, and blowing up the kiln with irresistible power.

De Garay, 1543.—Spain being in the meridian of her power about this time, transporting her armies across the ocean, became an object of great importance, when De Garay, one of her naval captains, proposed to propel ships by steam. The Romans transported Claudius Caudex's army into Sicily by paddle-wheel boats worked by oxen; and in 1472, Valturius describes two paddle-wheel galleys. The one had five wheels on each side, and each opposite pair connected together by a cranked axle. These cranks were again connected together, that the motion of the paddle-wheels might be simultaneous. The other boat had only one paddle-wheel on each side, fixed on a cranked axle.

Acquainted, probably, with this or earlier Homeric ideas or modes of moving ships, and ambitious to emulate the Romans, or, Joinville-like, invade our own envied shores (as was attempted by the Spanish Armada, in 1588), De Garay selected steam as his auxiliary. His plan was kept secret, but a steam-boiler was on board, and the paddle wheels were seen to propel the vessel. It might be done by a rotatory steam wheel, like Hero's, on the paddle shaft, or by a steam jet driving a central wheel, as in Fig. No. 60, or by a steam jet issuing at the stem against the resisting water, but below its surface. The result of a trial at Barcelona, before the Spanish court, was that a vessel of 200 tons burden was propelled about three miles an hour—no mean performance then—and now interesting from the progress of steam navigation. De Garay's success was honoured by the court; but his invention was *neglected.*

FIG. No. 60.



De Garay's Steam Boat, 1543.

From so many modern examples of neglected inventions it is more surprising that De Garay should have received honour for a successful experiment, than that his plans were not improved upon.

The republication of Hero's treatise at Bologna, in 1547, and at several other places, led many eminent men to suggest various modes of usefully employing steam and hot air, a few of which will be noticed.

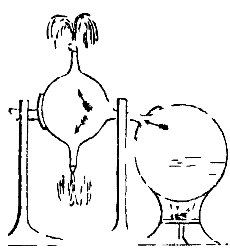
About 1548 Vitruvius refers to the steam from an æolipile as wind produced by heat; and Philibert de l'Orme proposed an æolipile to cure smoky chimneys.

Cardan, 1557.—The force of steam, and the rapid vacuum produced by its condensation, are both ably treated by Cardan, who also invented the smoke-jack, as still made, to illustrate the power of hot air. Possessing great scientific and superstitious knowledge, his life presents a singular blending of these together; as was also partially displayed in England by the Marquis of Worcester and other inventors.

Bressen, 1569.—An anonymous pamphlet, published at this time, on the expansive force of steam, is attributed to the pen of this celebrated mathematician and reputed author of a collection of machines, but published in 1578, after his death.

Matthesius, 1571.—In a sermon Matthesius illustrated the great effects produced by small things, by reference to the great power produced by heat from a small quantity of water. And in 1577, an observer in Soyer's useful *cuisine* department introduced a rotatory steam-engine, Fig. No. 61, to turn a roasting-spit, as a great and *clean* improvement upon the dog, previously employed to do so, but not always proof against "pawing" the savoury temptation beside him.

Fig. No. 61.



Roasting Engine, 1577.

In 1578, an English military writer, and in 1587, Paucerollus, both refer to paddle-wheel vessels as then in use.

Ramelli, 1588.—At this time another collection of machines was published yb this experienced engineer, which, along with that of Bressen, greatly promoted subsequent improvements in steam and other machinery.

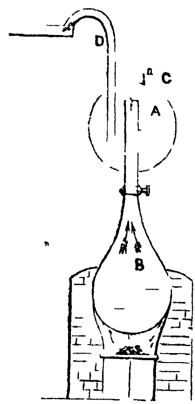
Platte, 1594.—Sir H. Platte still describes steam as "water attenuated by fire into air," which by its emission from a whirling æolipile, made of copper, blows a fire strongly.

He also suggested the collection of steam from domestic operations, and conveying it by pipes to force the growth of plants in a house near the kitchen.

Porta, 1601—1609.—Porta's plan of showing the relative volume and force of steam in raising water, was an ingenious one for his time.

The neck of the boiler B, Fig. No. 62, rises above the water in the vessel A, so that the steam generated in B may force the water out of A up the pipe D. The pressure of the steam was ascertained by weights on the valve C, and its relative volume by the ratio of the quantity of water forced out of A to that evaporated in B to force it out. Although not an accurate plan, still it shows a clear idea of obtaining that knowledge of steam which has so much engaged the attention of modern philosophers, as already explained, and was given by Porta as an improvement on Hero's fountain, Fig. No. 53. The popular magic lantern is Porta's invention.

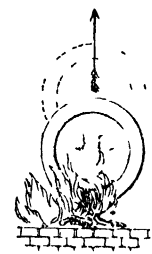
FIG. No. 62.



Porta s Engine, 1606.

Rivault, 1603.—Rivault shows a knowledge of the great force of steam, by his comparing it as equal to burst a bomb partially filled with water and placed on a fire, as in Fig. No. 63. The abutment or point of resistance to the escaping steam being in a line opposite to the fracture, the burst shell would be carried in that direction, as indicated by the arrow. Likewise, in any explosion of steam, the boiler would be forced in a line opposite to the fracture.

FIG. No. 63.



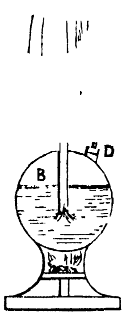
Rivault on the Force of Steam, 1603.

S. De Caus, 1612—1615.—There appear to have been two

De Caus's—a Solomon, the eminent engineer, and an Isaac, also a steam-engine historian. Solomon still describes steam as "water dissolved into air by fire," and its force as "infallibly bursting a copper ball containing water and exposed to heat."

He also discusses the evaporation of water by heat, and the condensation of such vapour by cold to its original volume of water again.

Fig. No. 64.



De Caus's Engine, 1612.

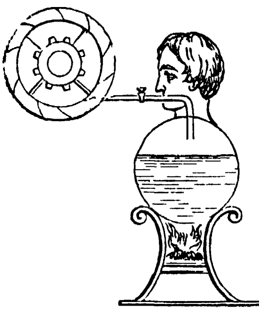
Fig. No. 64 shows his plan of raising water. As the steam is generated it forces the water below it at B up the pipe C. The pressure of the steam is regulated by the valve D, at which also the boiler was filled. For raising water, his plan is inferior to Porta's in economy, since the hot water is expelled from the boiler, losing both time and heat in generating steam again. Porta's, on the contrary, forces cold water from a separate vessel, and retains the hot water for steam, a difference greater, yet not much dissimilar to Newcomen's condensing in the cylinder, and Watts's condensing in a separate cylinder.*

Ramsay, 1618.—In 1618, David Ramsay obtained a patent for a new engine to plough without horses or oxen, to raise water and propel ships without sails; also in 1630, to raise water by fire from deep pits, move ships against wind or tide, and to fertilize the earth. We have not met with any lucid description or sketches of Ramsay's early ideas of ploughing, pumping, or sailing by steam or other motive power. Two out

* De Caus's sun-fountains are given, page 228, as illustrating the effect of the sun on water in idols.

of the three have been fully realized, and Lord Willoughby is now ploughing by steam at Grimsthorpe.

FIG. No. 65.



Branca's Engine, 1629.

Branca, 1629.—In his mechanical treatise, this distinguished physician describes a rotatory steam-engine he used for grinding his drugs. He gives the top of the boiler the form of a man's head with a pipe in his mouth, blowing a jet of steam against the arms of a wheel D, Fig. No. 65, to cause it to rotate on its axis, and by the pinion C give motion to the drug machinery.

A modification of this plan was recently tried at the Surrey Docks, with a wheel 11½ feet diameter, making 500 revolutions per minute. But the consumption of steam for an equal duty being greater with the rotatory than with a piston engine, led to its disuse.

Branca also describes a hot air rotatory engine, driven by the heat and smoke collected from a smith's forge, whereby to aid the smith in his operations; but all these engines he gives as the invention of others and not his own.

Drebbel, 1630.—The sounds emitted by the ancient idols are said to have been successfully imitated by Drebbel; introducing a little moisture with the air, their mutual expansion by the heat of the sun produced a "soft and pleasant harmony." This is closely following some of Hero's singing-birds illustrations, where the expansion of air by heat performs a chief part, aided by steam when required.

Beaumont, 1630.—Wood informs us that this enterprising gentleman expended about 30,000*l.* on introducing tramways amongst the Newcastle collieries. Their ultimate success led to modern railways, now exercising so vast an influence over the civilized world by means of the locomotive power of steam. This power it is our object to popularly explain; but it will be more generally instructive to trace the gradual improvements of the steam-engine, until the locomotive drops in as a young and powerful branch of an ancient family.

In 1632, amongst several other inventions, Thomas Grant included moving ships without sails; and in 1640, Edward Ford also proposed to move ships against wind or tide by some great power not clearly defined.

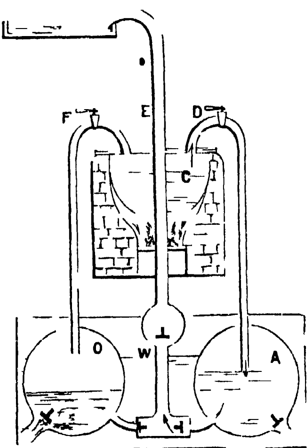
Wilkins, 1648.—In a contest of wit with the Duchess of Newcastle, Bishop Wilkins, besides other ingenuities, suggested the possibility of flying by "high pressure" steam moving large wings, which has been more than once attempted in modern times.

Marquis of Worcester, 1651—63.—On the fall of Charles I. in 1648-9, the Marquis fled to the continent, where he remained until 1656, when he returned secretly to London for Charles II., but was taken and imprisoned in the Tower. At the time of his exile, Hero's treatise had gone through five editions, besides the treatises of others already referred to; and when so much attention was directed to motive engines, it was likely to arrest the noble exile's notice when abroad. It is probable that from these sources most of his ideas originated, as afterwards given in his letter of 1651 to Hartlib, and in his hundred inventions of 1656.

In his writings and prayers, he thanked God for showing him "so great a secret of nature, beneficial to all mankind," yet he studiously withheld from mankind the construction of his "semi-omnipotent power," leaving it to be considered as a steam engine.

When a political prisoner in the Tower of London, this celebrated nobleman—after the example, but without the clear illustrations of Hero—drew up "The Century of Inventions." Of these the 68th refers to the steam-engine "as an admirable, most forcible way to drive up water by fire, which hath no boundes if the vessels be strong enough." He also compares the force of steam to the bursting of a cannon, evidently then, as it still is, a popular expression for a great force. No drawings or description of his engine have been found in this country; but in 1656, the Duke of Tuscany saw an engine lifting water 40 feet high, at Vauxhall. To the perplexity of readers, different authors have differently embodied the Marquis's description. Stuart and Galloway show a double De Caus engine, whilst Millington and Tredgold sketch a double Porta's engine, as in Fig. No. 66, where the steam from the boiler C passes down the pipe D, to expel the water from A, whilst O is filling with water at L, from the well W. The valves all open only one way, as in the sun-fountain. The cock in D is then shut and F opened, that the steam may expel the water from O up the central pipe E, whilst it is refilling again, and so on alternately to keep "one forcing whilst the other is filling," agreeably to the text.

FIG NO. 66.



Worcester's Engine, 1656.

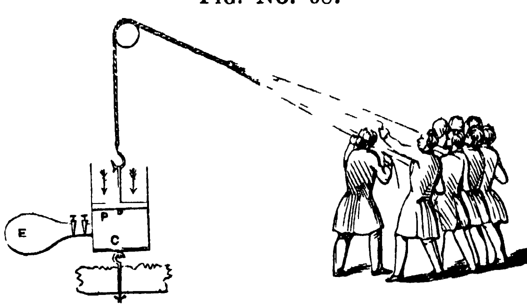
The Marquis also proposed to move ships by paddle-wheels against the wind or stream; but it is much to be regretted that he left no tangible evidence of his designs, such as is done by those preceding him in their illustrated works.

FIG.
No. 67.

Atmosphere raising water.

Otto Guericke, 1654.—This able man records some valuable experiments which illustrate the pressure of air in raising water, or in depressing a piston. In Fig. 67, the pressure of the air on the water in C is forcing it about 30 feet up the pipe A, previously exhausted of air, into the receiver E. If the vacuum had been perfect it would, as previously explained, have risen nearly 34 feet high.

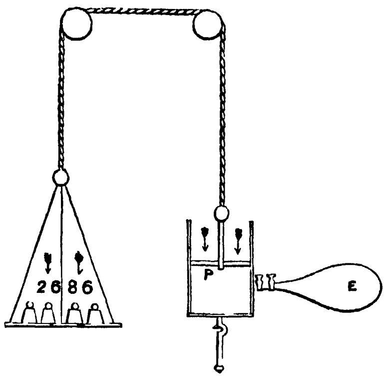
FIG. No. 68.



Man-power of Atmosphere.

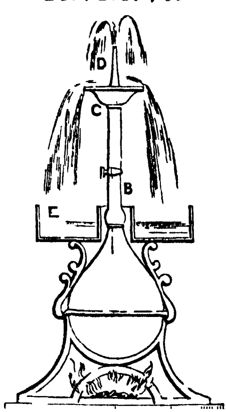
Fig. No. 68 shows the air pressing down the piston P (17 inches diameter) in the cylinder C, previously exhausted of air, into E, whilst a number of men are in vain exerting themselves to prevent its descent. Fig. No. 69 shows the pressure exerted balanced in a scale by 2686 lbs. The area of a 17-inch piston being nearly 227 square inches, gives 11·8 lbs. per square inch, or nearly the same as is obtained in a Watts's condenser. If the vacuum had been perfect, the pressure would have been $14\frac{3}{4}$ lbs. per square inch.

FIG. NO. 69.



Weight power of Atmosphere.

FIG. NO. 70.



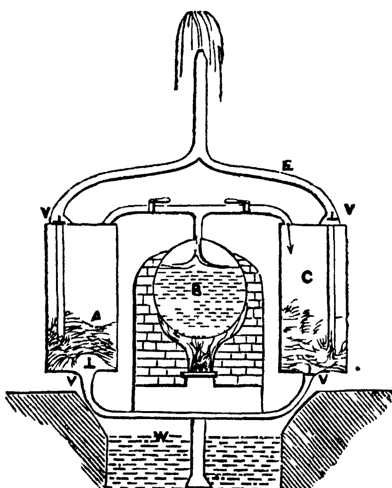
Kircher's Engine.

Kircher, 1656.—Kircher's illustration of Porta's plan might be made a pretty little fountain, by receiving the falling water in a cistern fitted round the stem B, and raised by atmospheric pressure to refill C again, as Fig. 70. He also suggested an improvement on Branca's engine, by having a blast of steam on each side of the wheel at the same time; and his models are highly spoken of as the workmanship of a mechanic named George De Sepi.

Jack of Hilton, 1658.—"Jack" is described as an artistic ælopile, resembling the human figure, with his right hand on his head, and his left hand "on pego," to blow the fire in Hilton Hall, whilst the Lord of Essington drove a goose three times round that fire before it was roasted for the Lord of Hilton, celebrated in Godiva procession annals.

Sir S. Morland, 1670—85. This distinguished mechanic wrote an essay (now in the British Museum) on the "Weight and Measure of Water elevated by Machines." His plan was by alternately filling and emptying two or more cylinders 30 times (or strokes) per minute. The duty he estimated by the weight raised in a given time, as is still done in this country. No drawings of his engine have come under our notice, but

FIG. No. 71.



Morland's Engine, 1680.

Fig. No. 71 embodies the description given of one with two cylinders. On steam passing from the boiler B to the cylinder C, it expels the water up the central pipe E, while A is filling with water from the well W, to be emptied in like manner whilst C is filling, and so on alternately. The relative volume of steam to water he gives as about 2000, and its force as capable of "splitting a cannon;" but being regulated by "statics and science to *measure, weight,* and *balance,*" it bears its load peaceably like a good horse, and becomes of great use to mankind.

He gives the following proportions of cylinders, and the weight of water they would raise each stroke. We have added the height in inches of the water raised equal to the diameter of the respective cylinders.

CYLINDERS.			WATER RAISED EACH STROKE.	
				Height in each cylinder.
No.	Diam.	Length.	lbs.	Inches.
1	1	2	15	3·7
1	2	4	120	7·4
1	3	6	405	10·0
1	4	8	960	14·7
1	5	10	1875	18·3
1	6	12	3240	22·0
2	6	12	6480	22·10

and so on to 90 cylinders, each lifting 3240 lbs. or 291,600 lbs. of water raised a considerable height per stroke. There can, therefore, be no doubt of Morland's clear appreciation of the nature of steam, and the method of estimating its performances. In 1675, he raised water from the Thames 60 feet above the top of Windsor Castle, at the rate of 60 barrels per hour, by eight men, which gave so much satisfaction, that in 1681 the King presented him with his medallion portrait set in diamonds.

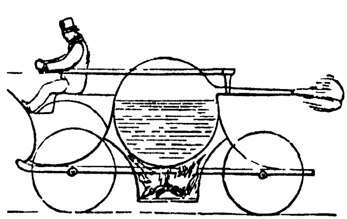
In 1678, Bushnel proposed to propel ships by oars bound together, and the rope ends fastened to the capstan, to be wound off and on alternately for each stroke of the oars, as afterwards tried by Fitch in 1788 with steam-power.

Hautefeuille, 1678. — This learned abbé and mechanist gave designs of engines for using heat, steam, gunpowder, and alcoholic vapour as motive agents. One plan was by direct pressure of steam or hot air on water; another by condensing the steam or vapour below the piston, to produce a vacuum for the atmosphere to force down the piston, as in Fig. 70; and a third was by exploding gunpowder on alternate sides of a piston.

With steam, Savary and Newcomen effected the first and second; but the third has not yet proceeded beyond experiment. A recent trial of gunpowder as a motive power, at Swindon Station, by James Squires—an ingenious mechanic and electric experimenter there—indicated that, as in shooting, the *débris* of the powder speedily choked up the moving parts, and arrested the engine. It was tried by fitting a separate powder-chest at each end of a small cylinder boring engine, and the powder was regularly admitted by a valve, and exploded by galvanic agency. The action was impulsive and not sustained, which, along with the deposit from the gunpowder, discouraged further trials.

In 1681 the Prince Palatine Robert's boat, propelled by revolving oars on the Thames, beat the King's 16-oar boat by a long distance. Papin was present at this trial. In 1682, a horse paddle-wheel boat was employed at Chatham for towing ships.

FIG. No. 72.



Sir I. Newton's Locomotive, 1688.

Sir I. Newton, 1680.—In his "Explanation of the Newtonian Philosophy," Sir Isaac Newton shows the elastic force of steam, by its locomotive capabilities, as Fig. No. 72, where the globular boiler B, with its steam-jet-pipe and cock C, is mounted "upon little wheels, so as to move easily upon a horizontal plane; and if the hole be opened, the vapours will rush out violently one way, and the wheels and the ball at the same time will be carried the contrary way." This is the first idea of steam locomotion we have met with.

The principle of producing locomotion by the velocity of one fluid acting against a fluid comparatively at rest has formed the subject of a patent by Allen in 1724, Rumsey in 1788, and Gordon in 1845. It was also the plan of Matthesius's roasting engine, Hero's rotatory engine, and various other inventions since that time.

Papin, 1680—1707.—This eminent physician and engineer proposed to apply steam to various purposes. Amongst others to dissolve bones, to throw bombs, to drive machinery, to propel ships, and to raise water. In his celebrated "Steam Digester" for dissolving bones into useful food, he employed steam of a temperature equal to melt lead, or about 612°. This indicates a pressure of about 1400 lbs. per square inch, which would propel either balls or bombs with very great force; for Perkins's celebrated steam-gun of 1838-9 only used steam of 410° Fah., or 450 lbs. pressure per square inch. To regulate the force of the steam in the digester he invented and employed the steelyard safety-valve C, Fig. No. 73. The lever C is jointed at one end to the valve seat, and the fulcrum is jointed centrally with the safety-valve on which it rests. The weight *a* presses the valve down by the fulcrum with more or less force proportioned to its distance from the centre of the valve. This valuable invention is still used in steam boilers in its original plan, although various similarly-loaded levers with shifting weights are shown in Hero's ancient designs.

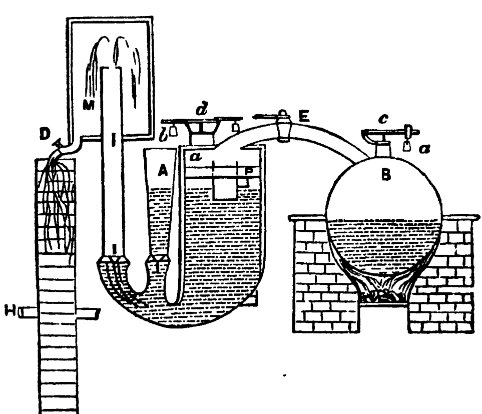
In 1687, at Marbourg, Papin constructed an atmospheric engine for raising water to drive a wheel, which also worked the air-pumps used for producing a vacuum in the long mine pipes, below the piston, as in Otto Guericke's experiments.

To render the action continuous, two cylinders were joined together by a two-way cock, which alternately opened each cylinder with the air-pump and the atmosphere. Each piston was connected by a rope to a shaft to give it motion, but the ropes were wound round in contrary directions, so that as one was raised the other was depressed; an arrangement adopted afterwards by Leupold for high-pressure steam.

Like that of the late promoters of the atmospheric railway, Papin's difficulty arose from the slowly obtained vacuum and leakages, which he failed to overcome.

His numerous experiments showed him the advantage of a good vacuum below the piston, which he sought to obtain in various ways; amongst others, by the explosion of gunpowder in the cylinder. This he abandoned as dangerous, and proposed to raise the piston by the steam, and then to condense it, that the air might depress the piston against a vacuum. He did not carry this out, but it was successfully done by Newcomen. Savary's success in England led the Elector of Saxony to recommend Papin to abandon his own superior proposal, and try Savary's plan. Fig. No. 73 is an outline of the result, which Papin calls the Elector's Engine.

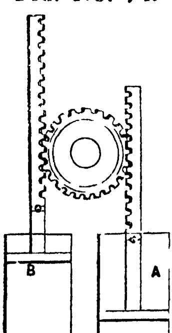
FIG NO. 73.



Papin's Engine, 1704.

Steam from the copper boiler B passes by E to the cylinder C and presses down the floating piston P, to force the water up the pipe I into the cistern M. The cylinder safety-valve was then opened to admit the steam to escape, and the water from the mine, aided by the air vessel A, refilled the cylinder again.* For driving machinery a water-wheel was added and the cistern M made air-tight. The outlet pipe D being smaller than the inlet pipe I, the air acting with the water was compressed and aided in keeping up a uniform force to turn the wheel H and produce a regular rotation. Even down to Smeaton's and Newcomen's time, this was an approved mode of rotation when available.

FIG. NO. 74.



Papin's Marine Engine.

For steam-ships he employed two or more cylinders, A B, having racks jointed to the piston rods, and arranged to gear alternately into the central pinion, P, on the paddle-shaft, and produce rotation. Several modifications of this plan were tried before the crank came into general use.

Papin first systematically tried to save fuel by improved boilers. One form was bent like a syphon, with the fire in the short end, and the draught down through the fire, whilst the cylinder was fixed on the long end, so that the heat acted on it in its passage to the chimney. The fire-bars were, however, so quickly destroyed by the intense heat, that it was called the "little volcano," and probably led Papin to recom-

* Air vessels are now used with much advantage in the construction of pumps for ordinary and locomotive use.

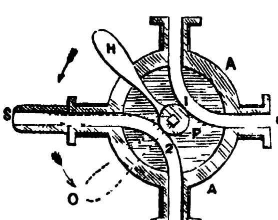
mend hot air for reducing mineral ores, as successfully done by Nelson in the present century.

Another boiler was 8 feet by 5 feet, with a tubular flue 24 feet long by 10 inches square, bent so as to pass four times through the water. This gives a heating surface of about 80 square feet, and led to a saving of about 75 per cent. of the fuel then used for ordinary boilers.

Although an account of this boiler, and other novel machines by Papin, was published in 1695 by Cassell, yet it appears not to have been known to Savary or Newcomen, since they used inferior boilers for their engines.

Fig. No. 75 is a sectional view of the useful and ingenious two-way cock of Papin, but usually called a four-way cock from the four external openings in the outside socket A A. The central plug P is fitted steam-tight into the socket A A, like an ordinary cock-plug, but has two passages 1, 2, through it, which alternately connect each adjoining pair of external openings, or shuts them all, as the plug is moved by the handle H one-eighth or one-quarter turn.

FIG. NO. 75.



Papin's Two-way Cock.

For a double-acting steam engine the passage S B leads from the boiler below the piston, and the passage T C from the top of the piston to the condenser, or to the atmosphere in high-pressure engines. By moving the handle H to S the passages are all shut; but when moved on to O, the boiler is connected by S T to the top of the piston, and the condenser by C B below the piston.

To equalise its wear, Bramah improved its form, and made the plug turn quite round within the socket.

It is thus seen that several important inventions and valuable suggestions, since reduced to practice, are due to Papin.

In 1699, boats propelled by revolving oars were tried both at Marseilles and at Havre, by M. Daguet, which were favourably spoken of.

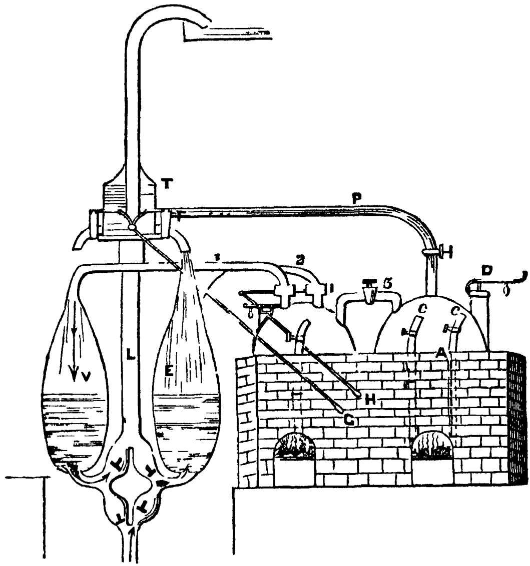
Amonton's Hot-air Rotatory Engine, 1699.—This was an ingeniously arranged box-wheel, 12 feet diameter, fitted with 36 air-tight cells, of which the 12 inner ones had valves opening upward only. In the lowest four of these valved cells were 750 lbs. of water, which was forced up one side by hot air, that its unbalanced gravity might give a downward motion to the wheel and produce rotation.

The action was by a tube conveying the hot air from each outer cell to each third lower water cell, to force its contents up through the valve in rotating, and as the wheel revolved its lowest edge passed through water to condense the rarefied air again. The fire was placed in a confined channel, to act directly on the outer air cells, resembling the position of a breastwater wheel; but instead of the downward water-flow, there was an upward hot-air action, yet both produce a similar rotation downward by the gravity of water.

The heat given out to the water by the hot air was thus lost, which in Ericsson's hot-air engine is mostly recovered, by exhausting it through wire gauze, and passing the cold air through this heated gauze to re-absorb the heat from it.

Savary, 1698—1702.—The great energy displayed by Savary in improving and introducing steam-engines added much to their popularity in England. His first engines were nearly the same as those already described, with the addition of cold water poured over the cylinder to produce a more rapid vacuum in it, but which had the bad effect of cooling it each stroke. He next improved the steam-admission valves, the mode of opening them, and his boilers.

FIG. No. 76.



Savary's Engine, 1702.

In Fig. No. 76, the two boilers are connected together by the pipe 3, and have gauge-cocks, C C, to ascertain the relative height of the water in them. The largest boiler, A, is filled from the water-tank T, and the small boiler is supplied with steam and hot water from A. The steam-pipes 1, 2, from B, convey the steam alternately to the vessels E V, to expel the water in them up the central pipe L, as in Morland's engines. When one of these, as E, has been emptied the cock F is opened by the handle G, and cold water poured over the vessel to condense the steam in it, and in like manner with V. The handle H conveniently regulates the steam-valves, and G the injection-cocks. One of Papin's safety-valves, D, regulated the force of the steam in the boilers.

It is related that Savary accidentally discovered the force and condensation of steam from a wine-flask—not quite empty

—being thrown on a fire and producing steam, when he took it off the fire and immersed its mouth below cold water, which condensed the steam and filled the flask by atmospheric pressure.

The labours of Worcester, Morland, and others in England, had so publicly shown the capabilities of steam, that in all probability Savary was fully aware of its force; but such an incident might suggest the mode of condensation he adopted, and which, applied internally, still exists.

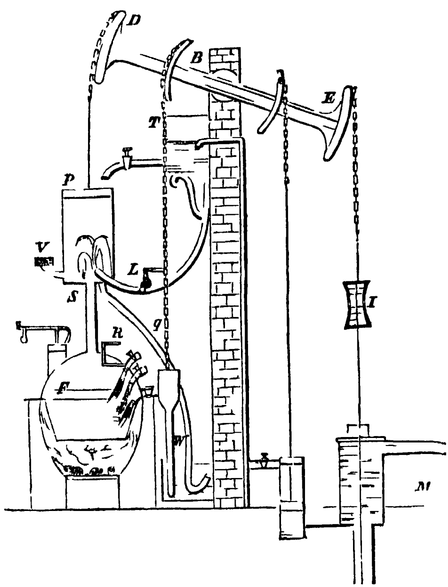
Savary states:—"My engine raises a full bore of water 60 or 70 feet high, and, if strong enough, I would raise you water 500 or 1000 feet high."

Only in the improved boiler and valve arrangements do Savary's engines exceed the idolatrous one, since the action of both is similar in passing from the boiler to two separate vessels, and expelling their contents out by other pipes.

Savary also proposed to propel ships by paddle-wheels worked by the capstan and suitable connecting ropes, which the Lords of the Admiralty referred to their surveyor, Mr. Dummer, who, like Sir W. Symonds in 1837, on Ericsson's screw-propeller, reported against Savary. Still unsatisfied, he persevered, until one of the commissioners thus faithfully expressed the sentiments of many in authority besides Government officials: "What business have interloping people, that have no concern with us, to pretend to contrive or invent anything for us?"

Newcomen's Atmospheric Engine, 1705—1720.—The exertions of Papin and Savary to bring the steam-engine into general use for draining mines stimulated others on in the same path, and amongst these Newcomen, a country blacksmith, honourably distinguished himself by his decided improvements on the steam-engine. Hitherto the air had only been used to fill the water-vessels, but on the principle, so clearly laid down by Otto Guericke, Newcomen employed the air to perform the principal duty, and steam only as an auxiliary. He also introduced the beam or balance lever, D E, Fig. No. 77, freely suspended on its centre, B. The piston P

FIG. No. 77.



Newcomen, 1705—1720.

was kept tight by a little water on its upper surface from the tank T, and was attached by a rod and chain to D, whilst a common lifting-pump M, leading to the mine, was attached to the end E. The cylinder was placed over the boiler F, and as the steam raised the piston, the counterpoise weight I lowered the pump-rod and bucket down through the water. The injection-cock L is then opened, and water admitted to condense the steam in the cylinder. The air passed out by V, and the condensed steam and injection water by the pipe Q, to the hot well W. Watt's principal improvement consisted in placing his condenser in the position of the hot well, and condensing the steam there in place of in the cylinder. By thus condensing the steam below the piston, Newcomen obtained a good vacuum, and the pressure of the air on the piston forced it and that end of the beam down, whilst the elevation of the other end raised the water from the mine. Steam was therefore only employed to raise the piston, and air to do the duty.

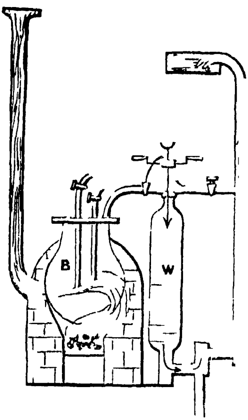
At first, Newcomen adopted Savary's plan of external condensation, but a faulty cylinder having admitted water internally, the condensation was more rapid, with increased effect from the engine. Since that discovery, internal injection has generally but not always been adopted.

The various cocks and valves were all opened by hand until Potter, a young lad attending one of the engines, ingeniously connected them to the beam by strings and catches, so as to open them with much regularity. Improved connections succeeded his temporary ones; still to Potter the credit is due of introducing the self-acting hand-gear.

The beam, the pump, internal condensation, and self-action were important additions to the previous steam-engines, earning for Newcomen and his assistants a well-deserved fame. We rejoice, therefore, to observe that it is intended to raise a suitable memorial for him in his native locality.

Desaguliers, 1717, 1718.—This learned doctor gave his preference to Savary's engines, and states that one erected at Petersburgh raised 2520 lbs. of water 40 ft. high per minute; and that another raised water 53 ft. high when making six strokes per minute, but only 35 ft. high when making nine strokes per minute. He also contended that they were more economical and effective than Newcomen's; stating that one of his engines, which cost 80*l*., raised 370 lbs. of water 38 ft. high, while one of Newcomen's, which cost 300*l*., only raised

Fig. No. 78.

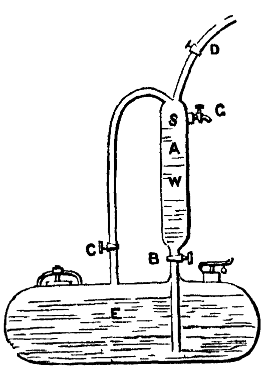


Desaguliers, 1717.

150 lbs per minute. Fig. No. 78 is an outline of Desaguliers' engine with its improved arrangement of boiler-flues; B the boiler, W the water, M the pipe to the mine. The action is similar to Savary's, but single acting.

Desaguliers' comparative statement merits some notice, since there was a constant loss of heat and time from Newcomen's chilled cylinders, amounting to about 30 per cent. of the whole steam generated. This source of loss would be little felt in Desaguliers', since water only slowly absorbs heat downwards. The following experiment, made by Goldsworthy Gurney, Esq , in September, 1850, at Westminster, in presence of several engineers, bears on these points, and may be instructive. Steam of 20 lbs. pressure above the atmosphere was alternately admitted in contact with cold water in the boiler-feeder A F, and in contact with air between the steam and cold water. Fig. No. 79 is a sketch of the boiler and feeder on which the experiment was made. It is used by Mr. Gurney for his steam-jet plan of ventilation in the law courts, so highly spoken of in the House of Lords. As no machinery was required, the boiler was supplied by water without a pump. The water-feeder, A, W, S, was connected to the boiler by the pipe B, and to an elevated water-cistern by

Fig. No. 79.



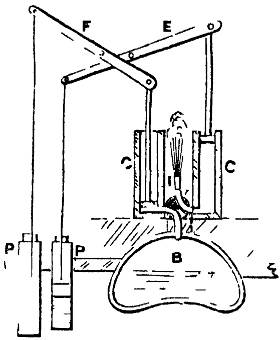
the pipe D. When it was filled D was shut, and B and C opened, that the steam might pass to the top of the water, and balance upward pressure below in B. The water then descends by its own gravity into the boiler.

When this feeder was partially filled with cold water, then air, then steam, cut off from the boiler at C, the air appeared to slowly absorb heat from the steam ; but when the air was expelled at G, and the steam remained in contact with the water, no perceptible absorption of heat from the steam took place. Even after this isolated steam had remained ten or twelve minutes in contact with the cold water, it blew off at G with much force. It was the difficulty of quickly condensing the steam which had done its duty, and not the condensation of the steam forcing the water, which retarded the action of these engines. Internal condensation was more rapid, but entailed the loss from a chilled cylinder each stroke. Besides, the unbroken surface of water rising up slowly against the steam would compress it and increase its force, as it does in the "back pressure" of a locomotive engine. Forcibly injecting broken water like rain amongst steam is a very different process, yet requires eleven times (or more, according to temperature) as much water to condense the steam as to generate it.

Beighton, 1718.—Potter's hand-gear was still further improved by Beighton, so as to open and shut all the valves and cocks with much precision. He also widened the top of the cylinder to prevent the water on the piston flowing off, and conveyed it by pipes to the boiler, or hot well, as it became hot. The action and arrangements of cylinder, beam, and pump were similar to Newcomen's.

Leupold, 1720.—Leupold recalled attention to high-pressure steam-engines by a very simple yet effective double-acting engine, Fig. No. 80. The steam generated in B passes alternately by the two-way cock I, to the cylinders C C, and raises the pistons connected to two beams which work the lifting-pumps P P, as in Newcomen's plan. A turn of the cock opens a passage for the steam to the atmosphere from one cylinder, and from the boiler to the other cylinder at the same time. The piston end of the beams are heaviest, to balance the weight of the pumps, that the pistons may descend by their own gravity.

FIG. No. 80.



Leupold, 1720.

This is given by Leupold as an improvement on Papin's atmospheric engine, similarly arranged.

Newcomen raised the water by atmospheric pressure during the downward stroke, but Leupold did so by steam pressure during the upward stroke of the piston, and the simplicity of this engine has rarely been surpassed.

Leupold also proposed an improved form of Amanton's hot-air rotatory, by using tubes instead of valves to connect the water-cells, which were also placed much nearer the periphery of the wheel to give greater effect to the raised water.

In 1724, John Dicken, and in 1729, John Allen, proposed engines to raise water, or move mills and ships. Allen's ship-propeller was by a jet of water or other fluid forced through the stern of the vessel below the surface of the water, whose resistance moved the vessel in a contrary direction, as in Sir Isaac Newton's locomotive-engine. This idea has been since tried by Fitch, in 1788, with water, and by Mr. Gordon, in 1846, by hot air, on the Thames.

Allen expressed his decided opinion in favour of a steam propeller of some sort as preferable to paddle-wheels, and more of the nature of the fish-tail propulsion.

To economise fuel with rapid generation of the steam, Allen proposed a fire-box boiler with a spiral flue through the water, and a bellows blast, to urge the "sluggish vapour" through the tube, as was done in Ericsson's Novelty Locomotive of 1829.

Gensanne, 1730.—By the gravity of water and the impulse of a falling weight, Gensanne made the steam-valve and injection-cock self-acting. On each end of a lever fitted to the water-cistern were water-buckets with a valve in the bottom, and in the cistern were also valves which the buckets opened, so that as one bucket was filled and descended by its gravity the other was emptied and ascended.

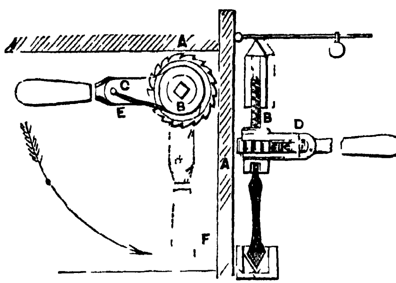
The bucket-valve was opened by the gab or fork of a bell-crank lever, which had a weight on its vertical end, and on beginning to ascend, the weight, or "tumbling-bob," was set at liberty, and the fork gave a smart jerk to the ascending levers.

The motion thus obtained was conveyed by another lever and parallel side-rods to open the valve by a gab or fork, and the injection-cock by a slotted lever, at the proper times. This is the first "gab" motion we have met with for working valves.

M. de Moura also constructed another self-acting apparatus of this class, but using a floating copper ball to give a motion outside corresponding to the rise and fall of the water in the receiving-cistern.

Jonathan Hulls, 1736.—We have seen that various modes of propelling ships by paddle-wheels or revolving oars had been proposed, using steam or other power to move them. In 1736, Hulls made a vigorous effort to apply a single-acting steam-engine to propel ships. This plan was to produce rotation by ratchet-wheels aided by a weight, whereby to move a central paddle-wheel in deep water, or two poles alternately thrust against the ground by a double-crank axle in shallow water. As the ratchet motion was much used until superseded by the crank, fly-wheel, and double-acting cylinder, its action will be explained by its modern adaptation to a very useful boring-brace in all confined corners, where a cranked-handled brace could not be turned round.

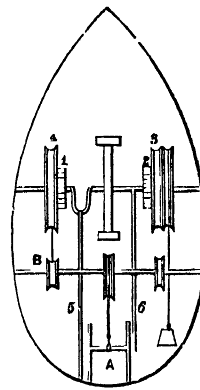
FIG. No 81



The ratchet-wheel A, Fig. No. 81, is fixed on the boring-spindle B. The detent or catch C is jointed to the handle D, and kept against the ratchet by the spring E. The handle moves freely round B towards A, without moving it, in the direction of the angle of the ratchet teeth, as the detent has no bite; but when moved in the contrary direction, the detent acts directly against the teeth, and carries round the ratchet and drill with it about one quarter revolution to F. The handle is then moved back to obtain another bite, and so on consecutively, but losing as much time in stopping as in rotating.

Now two handles with detents moved alternately would produce continuous rotation, and on this principle Hulls, Wasborough, and others obtained rotation from a single-acting cylinder. Fig. No. 82, shows Hulls' plan. A, the steam

Fig. No. 82.



Hulls' Steam Boat, 1736.

cylinder, whose piston is connected by a rope to the central pulley on B, and the two end pulleys by other ropes to the loose pulleys, 3, 4, on the paddle-wheel shaft, on which are fixed the ratchet-wheels, 1, 2, into which the loose wheel detents fall similar to the ratchet brace. As the air forces down the piston it moves B round one-quarter turn, and with it the paddle-shaft by means of the pulley 4, and ratchet 1. Steam is then admitted to raise the piston, when the weight W works round the pulley 3, and ratchet 2, to keep up the rotation of the paddle-shaft. In shallow water the cranked axle and pole 5, 6, were substituted for the paddle-wheel.

1739—1760.—In 1739, Belidor wrote a history of the steam-engine; and in 1741 Payne investigated the density of steam with considerable accuracy.

His spherical balloon-shaped steam-generator rested on its point, and had a vertical rotatory tube, through which water ascended to a horizontal tube above the generator, from whose ends it dropped on the top of the hot generator to produce spheroidal steam,—a plan again revived.

Experiments made at Newcastle and at Wednesbury are said to have realized the then high evaporation of 8 lbs. of water by 1 lb. of coals.

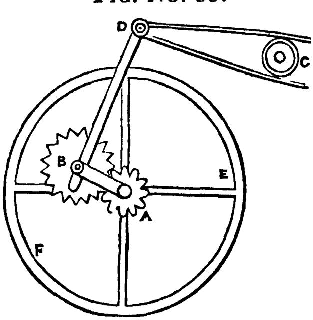
In 1740, Dr. Hale suggested and Fitzgerald tried to introduce air into steam boilers to promote economy, but their bellows were not sufficiently powerful to overcome the resistance of the steam.

In 1845, Mr. Wilkinson, and more recently Dr. Houston, have both patented modifications of this plan of combining air and steam to work an engine.

In 1751, Blake discussed the proportion of cylinders. In 1752, Bernouilli proposed an angular ship propeller on the principle of wind-mill vanes, to be driven by steam or other power: and in 1758, Emerson investigated the construction of steam-engines. In 1759, Brindley proposed stone and wood boilers, with cast-iron fireplaces and flue-tubes, to prevent loss of heat by external radiation. The bottom was of stone, and the sides and top of wood. Others were of stone or bricks, cemented together. From the internal fire copper tubes passed through the water to the chimney, as in modern locomotive boilers.

In 1757, as part of an improved plan of Papin's rotation by racks and pinions, Fitzgerald added the fly-wheel, which now forms a prominent part of fixed engines. To make it effective in regulating the velocity of the engine, it is made with light arms and a heavy rim, E F, that it may absorb power when the piston is at its greatest velocity, and give out its accumulated centrifugal force to continue the rotation when the piston has no velocity, at each turning point of its stroke. For instance, a stone swung round in a sling acquires a force which propels it beyond the limit which one unaided muscular effort of the hand and arm would have done; so, in like manner, the fly-wheel accumulates a force which continues the motion of the machinery when the piston itself could not do so. C D the engine beam, A B the sun and planet motion.

FIG. No. 83.



Fitzgerald's Fly Wheel, 1757.

In 1760, Genevas proposed a compressed spring propeller for naval locomotion, and a "winged cart" for land locomotion, which has been practically tried more than once during the present century.

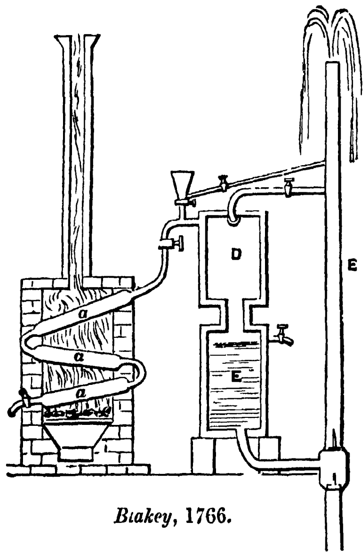
Dr. Black, 1762.—The properties of heat and steam were ably investigated by Dr. Black, who propounded the well-known doctrine of latent heat. A modern instance has been discussed of the extent to which the term "latent" is popularly used occured at the recent trial of the Midland Railway Company's servants, on account of a fatal accident. In answer to counsel, the Company's foreman stated his inability to speak positively to the condition of the piston, as it was "'latent' in the cylinder." On being asked what he meant by "latent," he replied, that if the learned counsel would place his papers inside his hat, on his head, he should say the papers were "latent" in the hat. In this sense the heat in steam may be called "latent," although known to be there in a diffused state.

Blakey, 1766.—Blakey introduced tubular boilers, containing the water in the small tubes, *a a a*, Fig. No. 84, round which the flame and hot gases passed to the chimney.

To keep the steam cylinder hot, he added an upper one, D, and employed air or oil as a piston between the water in E and steam in D. The rise and fall of the water in E he ingeniously arranged to open and shut the necessary cocks. The action was by admitting steam into D, which by its pressure on the aerial or oily piston forced the water out of E up the pipe F, and E was filled again from the well, as in Savary's engine.

This tubular idea of boilers has been successfully carried out, sometimes with the water surrounding the tubes as in locomotive boilers, or by having the water in the tubes as in Woolfe's, Gurney's, or Alban's boilers.

FIG. No. 84.



Blakey, 1766.

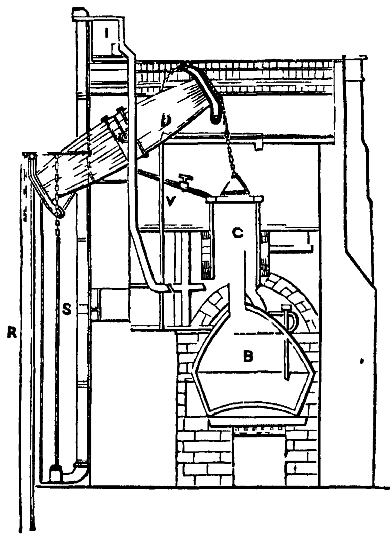
Smeaton, 1765.—The careful experiments made by this celebrated engineer reduced the performances of the steam-engine to the weight and measure suggested by Morland.

His experimental engine of one-horse power evaporated 6¼ lbs. of water by 1 lb. of coals, and required nearly 11 times more water for condensing than for generating the steam. It produced the greatest effect with a pressure of about 8 lbs. above the atmosphere. He also determined the relative steaming value of different coals, as given in p. 98, Vol. I.

This information enabled him to improve the various details of the atmospheric engine and its boiler, which he adapted for portable as well as for fixed duty. One of them, erected at Long Benton (Northumberland) in 1772, realized a duty of lifting 112,500 lbs. of water one foot high by 1 lb. of coals.

In 1775 he erected a very large one at Chacewater, having a

FIG. No. 85.



Smeaton, 1775.

cylinder of 6 feet diameter and 10½ feet stroke. The beam D was made of twenty pieces of timber strongly bolted together. The cylinder C was firmly fixed to the side beams 1, 2, as well as on its end supports on the boiler B. The mine pump was attached to the rod R, and another pump S raised water to the cistern I, from condensation by injection into the cylinder. The rod V worked the steam and injection-valves.

The action of the engine was the same as in Newcomen's, air being the principal motive power.

In some of his boilers Smeaton inclosed the fire, and supplied the fuel by a feeding-tube, with the then good results of 7·88 lbs. of water evaporated by 1lb. of coals.

Cugnot, 1763—1771.—In 1763 this French engineer made a model of a steam locomotive, and in 1770 the French government had one constructed at the Paris arsenal, tried in 1771, and then *laid aside*. Through the favour of Monsieur Morin, Director-General of the Conservatoire of Arts and Machinery in Paris, illustrations of this first piston locomotive engine practically tried will be given in the next chapter.

The piston rods worked downwards, as afterwards adopted in Cornwall by Bull, to evade Watt's patent, and now in pendulous engines by various makers.

The inventor became reduced to poverty, and had a small pension from government; but the revolution stopped this, and a humane lady of Brussels relieved him until Napoleon granted him a larger pension than he had lost, but still only about 42*l*. yearly.

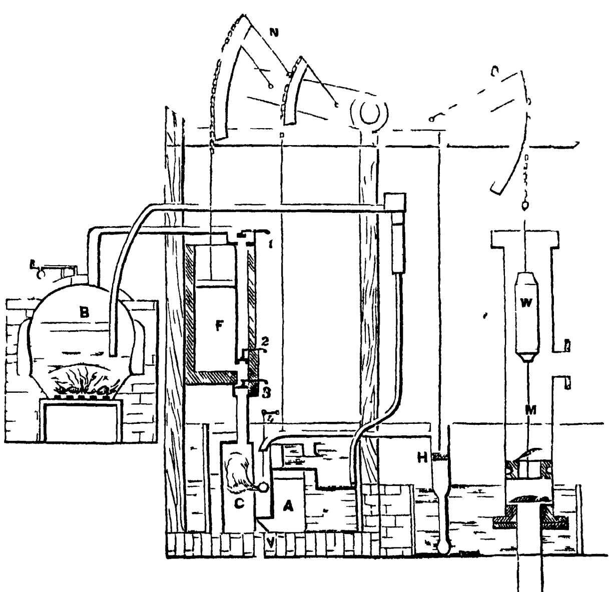
Watt, 1762—1800.—This very distinguished mechanical engineer was born at Greenock, in 1730, and died at his residence near Birmingham in 1819, after a long life spent in adding immensely to his country's resources. At Glasgow he became early acquainted with Dr. Robison, who, in 1759, suggested to Watt the application of steam to propel wheeled carriages. Like the earlier idea of Sir Isaac Newton, that steam could be made to produce locomotion, this suggestion was not practically followed up. The value of Britain's mineral produce rendered the application of steam to clear mines of water a more immediately interesting subject, to which Watt directed all his energies, with a success which astonished the world; the leading defect of Newcomen's engine, as imprcved by Smeaton, was the loss of heat arising from condensing the steam in the working cylinder. By careful experiments it was found that this loss amounted to about 32 per cent.; the steam being condensed in reheating the cylinder each stroke, besides the loss of time in doing so. In this state Watt found the steam-engine, and by his vast improvements stamped his name upon it as if it had been his own original invention.

On models of Papin's high-pressure and Newcomen's low-pressure engines he tried several experiments, which from apprehension of danger from high-pressure steam, determined him in favour of low-pressure engines.

This opinion still largely but unfairly influences society, as is evident by the success of high-pressure locomotives on railways working with steam from 80 lbs. to 130 lbs. pressure per square inch.

After several trials on condensing the steam in another vessel connected with the cylinder, in 1769 Watt patented the addition of a separate condenser, C, Fig. No. 86, to Newcomen's engine. The condensed steam, injected water and

FIG. No. 86.



Watt, 1769.

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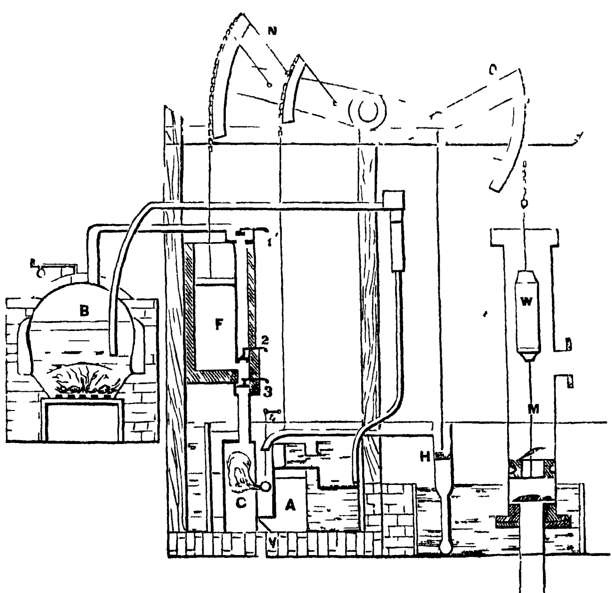
FIG. No. 86.



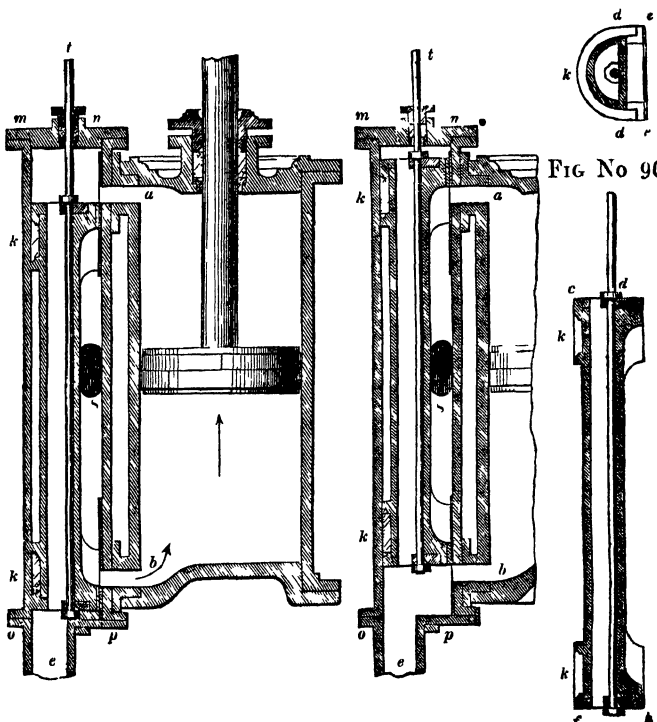
Watt, 1769.

air were withdrawn from the condenser C, through a foot valve, by the air-pump A, to the hot well, from which a feed pump supplied the boiler B. The pump H supplied the condensing water to the cistern, in which the air-pump and condenser are fixed. The conical steam-valve 1, the equilibrium passage-valve 2, the condenser passage-valve 3, and the injection-cock 4, were all opened and shut by suitable levers worked by the air-pump rod. To maintain the temperature of the cylinder equal to that of the steam, Watt closed its top with a cover, having a central stuffing-box through which the piston rod worked steam-tight. He also surrounded it with a "jacket" of wood or other non-conducting material, having steam between the jacket and cylinder. The air being thus excluded from the cylinder, the steam had to perform the duty done by the air in Newcomen's engine. The steam, therefore, entered by the top valve 1, to press down the piston and raise the water from the mine by the pump M, and to the boiler and injection-cistern by their pumps. The equilibrium passage-valve 2 was then opened, that the steam might pass to both sides of the piston, and the counterpoise weight W raise it and the air-piston to the tops of their respective cylinders again. The equilibrium passage-valve 2 was then shut, and the steam-valve 1, condenser passage-valve 3, and injection-cock all opened, that the steam below the piston might pass to the condenser, and steam from the boiler to force down the piston again, as seen in the figure. The air-pump kept a vacuum in the condenser equal to about 12 lbs. pressure per square inch, which with rapid condensation and a hot cylinder saved the 32 per cent. lost by condensing in the cylinder, besides the gain in time—a very important step in advance of previous engines. Still this engine was only single-acting, that is, giving out power during the downward, but none during the upward stroke of the piston.

Watt also proposed a rotatory engine, by having a piston working round a circular channel connected with the boiler and condenser, with valves which were opened and shut by the steam and piston; but the valves were found to fail, and the piston to be injured in passing over the ports. Another plan was, by causing the steam to raise water through valves, as in Amonton's hot-air rotatory, but it was found to give out only a limited power. The double-acting cylinder was then invented, as supplying much of what was sought for by the rotatory class of engines.

Fig. No. 87. Fig. No. 88. Fig. No. 89

Fig No 90



Watt's Double-Acting Cylinders, 1782, *and Murdock's Slide Valves*, 1799.

By making the equilibrium-passage a steam-pipe or chest to admit steam alternately above and below the piston, with equal facility of escape to the condenser, in 1782 Watt made the steam both raise and force down the piston, thereby giving out power in both directions. This judicious improvement constitutes the double-acting engine. Fig. 87 is a sectional view of a double-acting cylinder, having the steam entering at S and passing by *b* below the piston, and the condenser passage *a e* open to the top of the piston.

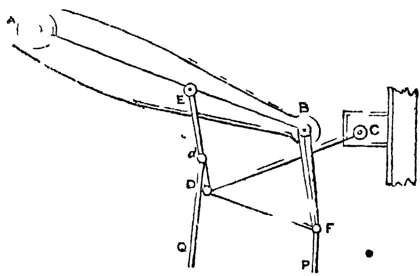
In Fig. No. 88 the steam-passage is open by *a* to the upper side of the piston, and the condenser-passage by *b* from below the piston. The conical valves, as in Fig. No. 86, worked from the beam, opened and closed the steam-passages until Murdock, one of Watt's able assistants, introduced the eccentric motion and long D slide-valve in 1799.

Figs. 89 and 90 are sections of the long D slide-valve. The flat faces *h i* slide over the cylinder steam-passages *a b*, alternately opening them to the cylinder, and from the cylinder to the condenser. The convex stuffed faces *k k* press slightly against the steam-chest cover to keep the faces *h i* steam-tight over the passages or "ports" (as they are called) leading to the cylinder.

Whilst the single-acting force was downward, a chain conveniently connected the piston rod to the beam, but as a flexible chain could not communicate upward motion, Watt tried a racked piston-rod worked by a toothed sector on the beam end. This proving noisy, and being easily deranged, in 1784 he patented the beautiful arrangement of levers, called the parallel motion, whereby to connect the vertical motion of the piston-rod to the circular motion of the end of the beam. By making A E and C D, Fig. No. 91, of equal lengths, but moving in opposite fixed centres, A C, the convexity of their equal curves would be opposite each other, when the centres A C were in the same plane.

On connecting them together by the link E D, its centre would move nearly in a right line. Another nearly vertical

FIG. No. 91.



Watt's Parallel Motion.

point is obtained by making B F equal to E D, and D F to B D. The centres of E D and B F would then move parallel to each other, but as B is a greater distance from the centre of motion, A, than E is, it would move through a greater height.

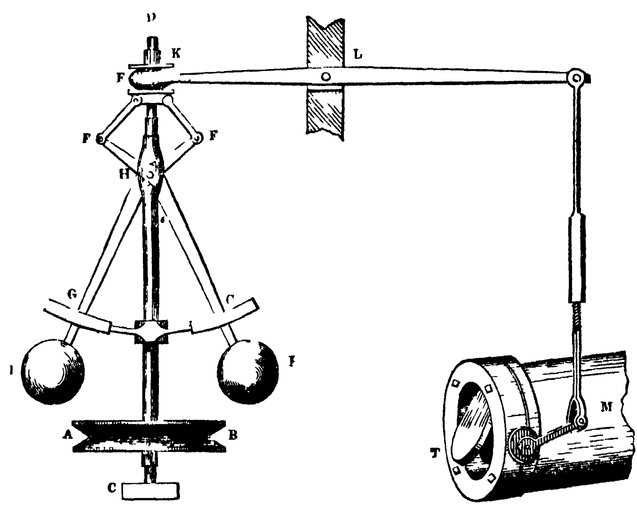
In practice, the radius rod centre, C, is fixed near the line of the piston-rod, and the length of B F below the plane of A, that the links may be arranged to make F *d* the neutral points of the opposite curves.

The piston-rod is usually attached to the point F, and the air-pump rod to the point *d*, but the points may be varied according to the stroke required.

Parallel motions for beam engines, more geometrically accurate but also more complex than Watt's, have been proposed and some of them tried, but failed to compete with it for simplicity and durability. To guard against irregular generation of steam affecting the motion of the engine, Watt introduced the throttle valve, worked by the governor previously employed in corn mills to regulate the velocity of the stones.

In Fig. No. 92 the vertical shaft D is connected directly by the pulley A B to the fly-wheel shaft, that their velocities may be proportional to each other. The balls I I are jointed to D at H, and by the short levers F F to the sliding socket

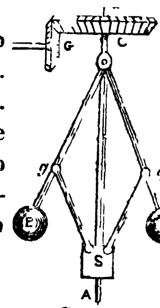
FIG. No. 92.



Governor. *Throttle Valve.*

H The lever E N moves on its centre L, and connects the sliding-socket H to the throttle-valve T in the steam pipe M. When the velocity of the engine increases, the balls recede from each other in the guides G G as they accumulate centrifugal power, and draw down the socket H, which by the lever E partially closes the valve, as in the figure, and checks the flow of steam to the cylinder. When the velocity of the engine decreases, the balls approach each other and raise K as they give out their acquired power, which opens the throttle-valve for a free admission of steam to the cylinder.

Fig. No. 93.



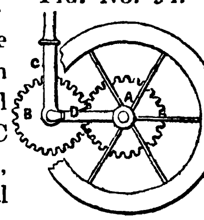
Governor.

Another form is by connecting the balls to the upper part of the vertical shaft, A *a*, Fig. No. 93, with the sliding-socket, S, below. Single links, *g g*, then connect S with the balls, and bevel gear, C G, either at the top or below, connect the governor with the fly-wheel. The action of the governor is both delicate and good.

Combined with Fitzgerald's fly-wheel, these admirable inventions made the steam-engine so regular in its movements, that it became very desirable to apply it to give motion to machinery. Papin, Hulls, Masborough, Watt, and others, had all given more or less attention to convert its reciprocation into rotation, with no better result than the ratchet rotation, when James Pickard solved the problem in 1780 by applying the crank and connecting-rod to the steam-engine. He afterwards entered into partnership with Wasborough of Bristol, and several engines were erected under Pickard's patent.

Watt, however, complained that the crank was a part of his design, unfairly obtained through one of his workmen, but rather than cause litigation he invented and used the sun and planet rotatory motion during the existence of Pickard's patent, which rendered it of comparatively little value to the patentee, although a valuable arrangement.

Fig. No. 94.



Sun and Planet Motion.

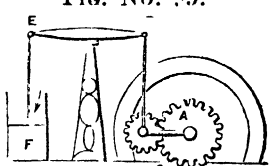
The peculiar action of the sun and planet motion is deserving of notice. The sun wheel A, Fig. No. 94, is fixed on the fly-wheel shaft, and the planet wheel B is attached to the connecting rod C leading to the beam. A separate link, D, connects the wheels A B of equal diameter and teeth together, that they may be in gear at all parts of their revolution. Planet-like, the wheel B revolves round the central wheel A, and as the centre of B's circuit is the periphery or circumference of A, the ratio of the diameters of their respective circles of revolution is as 2 to 1. Hence the sun wheel revolves twice round its own axis whilst the planet wheel revolves once round the sun wheel.

This is an advantage not possessed by the crank for working with a slow motion of the piston and light fly-wheel. The crank is, however, more simple and durable, which has led to its general adoption for converting reciprocating into rotatory motion.

After the first successful application of steam-engines to machinery, more graceful forms and superior finish were given to the various parts by Watt, until the steam-engine became a beautiful as well as a useful machine.

Little alteration either in the action or details of condensing beam-engines has taken place since Watt's time. It may however be remarked, that one of his best engines applied to Mr. Lacy's flour-mill, at Birmingham, was found to produce more coarse flour in grinding wheat than was done by water power. This irregularity of motion was cleverly remedied by Mr. Buckle, one of Watt's pupils, and now of the Mint, London. To the fly-wheel shaft, A, by means of the toothed wheels, B C, and lever D E, he connected an atmospheric cylinder, F. The wheel B had twice the number of teeth in C, that their revolutions might be made in equal times. When the velocity of the engine tended to increase, it had to raise the piston, P, against the air, but when the velocity tended to decrease, the pressing the air on P gave out power to B. This greatly improved the regular action of the engine, and secured the desired end of increasing the proportion of fine flour.

FIG. NO. 95.



Buckle.

Small engines dispense with the beam and use fixed guides for the parallel motion. They are variously arranged according to taste or the duty required, but are all double-acting and alike as regards the action of the steam. Boilers have varied and still vary considerably. Newcomen and Smeaton employed a circular form with a convex top like a hay-cock, but Watt adopted a form resembling a covered waggon, from which it took its name. By improved flue and other arrangements the evaporation was increased to 8·6 lbs. of water by 1 lb. of coals, or 9·4 per cent. more than Smeaton's.*

Fig. No. 96 is a transverse, and Fig. No. 97 a longitudinal section of a waggon boiler, with its modern self-acting feeding apparatus. One mode of feeding a high-pressure boiler without a pump has been explained by Fig. No. 79, and the plan of feeding a low-pressure boiler by its own action without a pump now claims our attention. The principle is by a column of water equal in weight to balance the pressure of the steam in the boiler. As has been shown, a column of water 34 feet high has a pressure of $14\frac{3}{4}$ lbs. per square inch, which gives 2·3 feet high for each 1 lb. of pressure in the boiler above the atmosphere, or 23 feet for 10 lbs. pressure, besides the allowance necessary in practice. At the top of this columnal pipe *l*, and between it and the water cistern, a valve *k* is fitted, and kept in its seat by the weight *w*, whilst the other end of the lever *v* is connected to the stone float *m* in the boiler.

* It may be mentioned here, that in 1782, Mr. Achard, and in 1790, M. Bettancourt, investigated the comparative properties of the vapours from water, and from alcohol.

In 1790, M. Pronig wrote on the steam-engine, on the force of steam of different temperatures, and on combustion.

In 1793, Mr. Curr had an engine constructed on Savary's plan, which raised 120,000 lbs. of water one foot high by 1 lb. of coals, or about one-half of what Watt's engine did.

In 1795, Mr. Banks wrote on the useful effect of atmospheric engines; and in 1803, on the strength of the parts of engines.

In 1797, Mr. Curr gave the proportions for a 61-inch cylinder engine, capable of lifting 130,000 lbs. one foot high, by 1 lb. of coals; and in 1801, Mr. Dalton published tables of the force of steam of different temperatures, which with Mr. Southeron's steam tables, have only recently been superseded by those of M. Regnault, of France.

FIG. No. 96.

Waggon Boiler—Transverse Section.

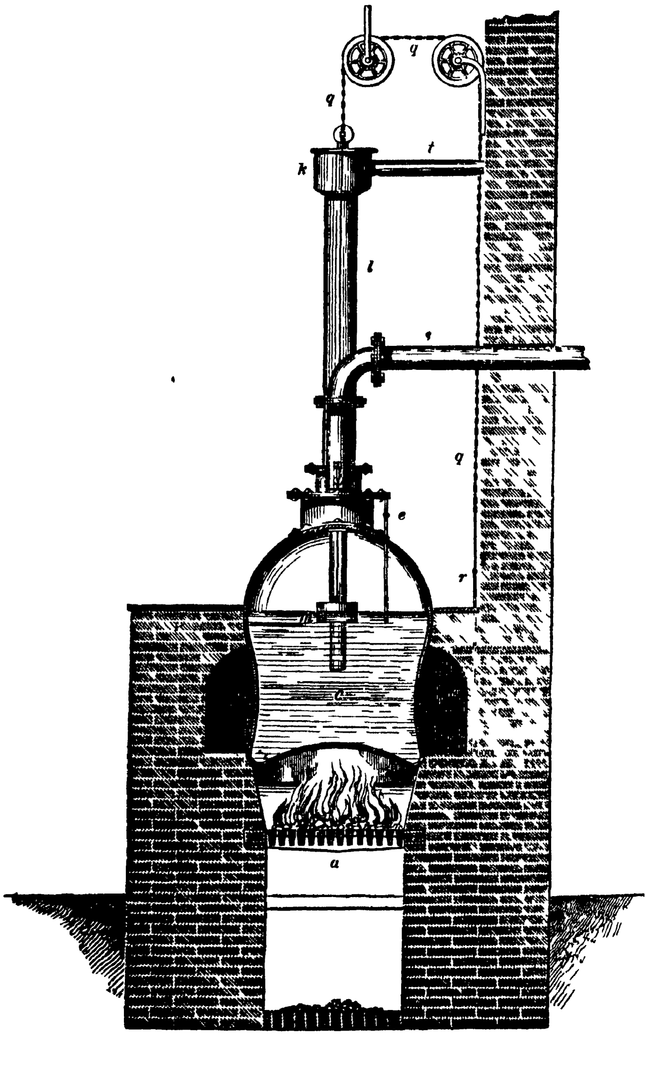
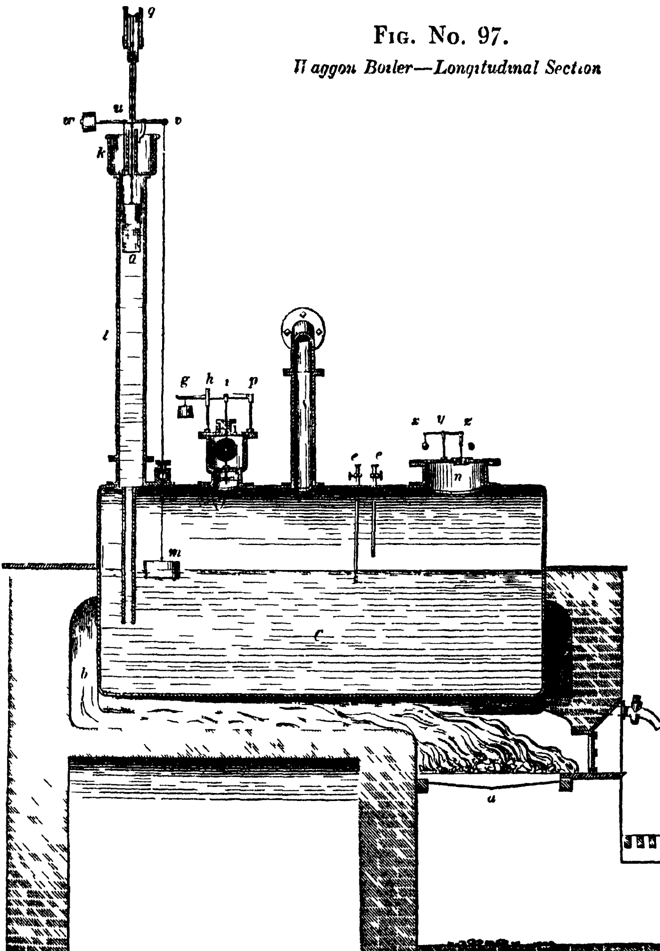


FIG. No. 97.

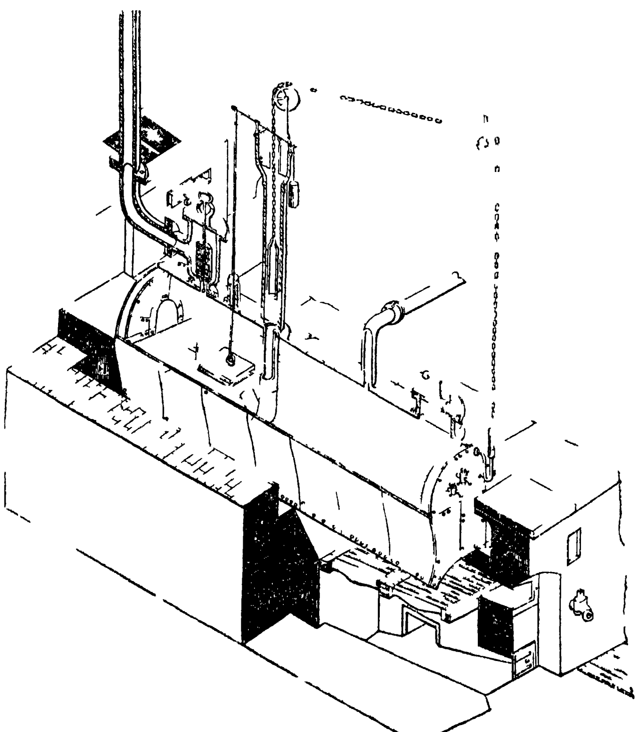
Waggon Boiler—Longitudinal Section



When the water falls low the float follows it and opens the valve *k* to admit water, but when the water raises the float the tension on *v* is relieved, and the valve *k* is closed by *w* to exclude the water. The water in the boiler is thus made to regulate its own supply. The flue dampers is also ingeniously worked by the float *o*, in the column of water in *l*, passing by a line over the pulleys *q q* to the damper The height of the water in *l* depending upon the pressure in the boiler, when that pressure increases and raises the water the damper falls and partially shuts the flue to check the draught on the fire, but if the steam pressure decrease, the water falls and the damper is raised to increase the draught and combustion. Two steelyard safety valves *g*, *h*, *i*, *p*, and *x*, *y*, *z*, regulate the pressure in the boiler *e*, *e*, the gauge-cocks. S the steam-pipe leading to the engine

FIG No 98 is a perspective view of the complete self-

FIG No 98



acting waggon boiler, partly in section to show the water, fire-grate, and construction. To the left is shown a mercurial syphon gauge, and a glass gauge is also now usually placed in front to show by sight the height of the water in the boiler.

FIG. No. 99.

Fig. No. 99 is a glass gauge employed both on locomotive and stationary boilers, that the height of the water may be seen. *a a*, two stuffing-sockets, into which the glass tube is fitted steam-tight. It is connected to the front of the boiler by the cocks *r r*, and the cock *s* is for blowing through the tube or clearing it. The lower cock admits the water, and the upper one the steam, that their relative position may be the same in the tube as in the boiler. The water should always be some height in the glass tube, and at a recent fatal accident at Bristol the witnesses remarked that the boiler was out of gauge, signifying that the water could not be seen in the glass. This is a dangerous state, requiring careful but instant precaution to be taken to prevent an accident.

In 1776 Watt introduced the expansive action of steam cut off from the boiler, at Soho and other places. He calculated that when cut off at half-stroke the performance would be as 1·7, at one-quarter stroke as 2·4, and at one-seventh stroke as 3 in economy as compared with admitting steam during the whole length of the stroke. In 1778 one of them was erected at Shadwell water-works, and in 1781 Hornblower patented the same principle, but expanded the steam in a second cylinder, which led Watt to patent his single-cylinder plan of expansion in 1782. The advantages and comparative merits of these plans have been illustrated under the head of the expansive force of steam, showing the practical result in favour of Hornblower, although the absolute power given out is in favour of Watt's single-cylinder plan.

A locomotive engine and a steam indicator were also amongst Watt's inventions, and will be described under their respective heads. The indicator is said to have been suggested by his assistant, Mr. Douglas.

We have pointed out that the generation of steam and its economical employment were two distinct processes, each requiring to be duly attended to. This is very clearly shown in Watt's success, and also in the more recent corresponding success over Watt's engines. His first double-acting engine, erected at Albion-mills, London, realized a duty equal to raising 229,971 lbs. 1 foot high, or rather more than double Smeaton's Long Benton engine. Yet there was barely 10 per cent. of this gained by Watt's boiler, leaving 90 per cent. due to the more economical application of the steam after it was generated.

With such able rivals as Smeaton, Hornblower, Trevithick, Bramah, Wasborough, and others, often disputing the validity of his patents, or seeking to evade them, Watt's ultimate success has imperishably associated him with the steam-engine.

It should not however be forgotten, that but for the business habits and ample fortune of Boulton, his partner Watt could not have maintained a struggle which involved an expenditure of about 78,000*l*. to defend his patent rights and introduce his engines before any profit was realized. This enormous expenditure led to a renewal of his patents by the Privy Council.

For an elaborate description and engravings of Watt's improved engine and modern examples, see the 3rd edition of Tredgold on the Steam Engine.

1774—1800.—During the time that Watt was carrying out his steam-engine improvements other engineers were also engaged in the same field, both in France, in America, and in Great Britain, some of which will be noticed.

In 1774, Compte Auxeim and Perrier, of France, constructed and tried a paddle-wheel steam-boat, but did not persevere with it. In 1776, Bushnell, of America, proposed a screw propeller for ships, which gave them a backward or forward motion, by reversing the revolution of the screw.

In 1776, Wasborough, of Bristol, a rival of Watt, proposed to propel ships, raise water, or drive mills, by steam-engines with a ratchet-wheel rotation.

This enterprising engineer erected several of this class of high-pressure engines, and in 1781 was desired to fit one up at Deptford for the government, where soon after Watt appeared as a competitor, and Smeaton as a consulting engineer. On the ground that no reciprocating lever could produce "perfect circular" motion, Smeaton recommended that a water wheel should drive the machinery, and a steam-engine raise the water to drive the wheel.

In 1781, a steam-boat 140 feet long was successfully worked on the Soane in France by the Marquis De Jeuffrey.

Hornblower, 1781.—The introduction of Watt's pumping engines into Cornwall, accompanied by Murdock, excited much local emulation to compete with or excel them, which has led to the great economy of modern Cornish engines. Amongst those local engineers, Hornblower, during Watt's patents, and Trevithick, principally after their expiring, most distinguished themselves.

In 1781, Hornblower patented a judicious arrangement of an additional cylinder, wherein to employ the expansive force of steam after it had done its duty in a smaller cylinder, on the plan of two cylinders, first suggested by Dr. Falcke, for the expansive action of steam.

For a section of the cylinders as improved by Woolfe, and their comparative value to a single-cylinder engine, see Fig. 51, page 208.

The principle of expansion, the condenser, cylinder-passages, and details were all so similar to Watt's single-acting engine, that after a law-suit he obtained payment for the use of his patents in Hornblower's engines, which were also only of the single-acting class.

The beam, mine-pump, counterpoise-weight, and chain connection being similar to Watt's, need not be further described.

Besides Hornblower, various engineers attempted to construct efficient engines without infringing Watt's patents, but they nearly all failed to do so with low-pressure steam without a separate condenser.

Hornblower's rotatory engine had two moveable pistons alternately moving round the steam cylinder, and acting as abutment valves to each other. A tappet valve in each piston was opened as it came in contact with the abutment one, which was then also set at liberty, and the other arrested by sliding levers behind it, and so on alternately.

Bramah, 1783—1797.—Bramah, another rival of Watt, proposed to propel ships either by paddle-wheels or by a screw, on the principle of the smoke-jack vanes. He also improved the construction of the two-way cock of Papin, by making it turn quite round, to equalise the wear.

His letter of 1797 to Sir J. Eyre, Chief Justice of the Common Pleas, strongly urging the demolition of Watt's patent, is one amongst many instances of one engineer seeking by casuistical pleading to injure another from interested motives.

Bramah's chief objections were, that Watt's engine was much more complete than the specification in details, more particularly in, 1st, the cylinder top being closed; 2nd, ingenious piston and valve-rod stuffing-boxes in the covers; 3rd, gun-metal valves curiously worked; 4th, stoppage of the engine by any one defect; 5th, construction of stuffing-boxes; 6th, cylinder bottom closed, and steam acting above and below the piston; 7th, the "cuning" condenser, valves, and pumps. He concluded by declaring his inability to make an engine by the specification, and that the patent was thus invalid, but he failed in the attempt to convince the Court.

Bramah also proposed three varieties of a rotatory engine, by a piston moving round a steam chamber divided into two parts, alternately opened to the boiler and to the condenser by slide valves working at right angles to the piston, and alternately pressed against it by an eccentric motion. He is, however, now chiefly distinguished by his valuable hydraulic press and celebrated lock, requiring so much skill to pick, at the Exhibition, by that clever artist, Mr. Hobbs.

Fitch, 1783—1788.—In 1783, Fitch, an American, proposed a steam-boat with six oar-propellers on each side, and so arranged that each opposite three should work simultaneously, and enter the water as the other six were leaving it. Motion was given to the oars by a steam-engine with twelve-inch horizontal cylinder and three-feet stroke, working a wheel eighteen inches in diameter, suitably connected to the oars. In 1783, he moved a boat by paddles on the Delaware: and on trial at Philadelphia, in 1789, a speed of eight miles an hour was obtained; but Fitch's supporters having left him, he fell into poverty, and in despair drowned himself.

Rumsey, 1784—1793.—Rumsey's American steam-boat was propelled either by poles in shallow water, as on Hull's plan, or by pumping water in and out of a pipe along the bottom of the vessel. The pump was two feet diameter; and during the upward stroke the water entered by a valve, which was shut by the returning stroke, and the water expelled at an orifice about six inches square in the stern of the vessel. In 1793 a speed of four miles an hour was realized on the Thames, against the wind and tide, by one of Rumsey's boats.

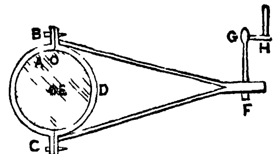
Oliver Evans, 1784—1804.—While Watt was devoting his talents to the steam-engine in Great Britain, a kindred spirit in America, Oliver Evans, was devoting all his energies also to extend its usefulness in the New World. Watt preferred low-pressure steam; Evans, high-pressure steam; and ever since both nations have generally followed the guidance of these leading men. The low-pressure engine is most complex, requiring an air-pump condenser and injection-pump, more than is required by a high-pressure engine, where the steam escapes into the air, as daily seen from locomotives.

Strongly impressed with the locomotive capabilities of high-pressure steam-engines to move ships or waggons, in vain Evans sought to obtain pecuniary means to test his ideas. His locomotive opinions were derided as emanating from insanity, consequently he found no Boulton to aid genius struggling against poverty and prejudice in those fields of steam enterprise now so prominent throughout the world. He introduced the superior cylindrical boiler with an internal flue, and leading back below the boiler to the chimney. To further economise fuel, the exhausting steam was made to pass spirally through a pipe in a cistern of water to heat it for the boiler, as also done by Trevithick afterwards.

In 1804, he showed the capability of his engine for both land and river locomotion, by temporarily fitting one of them on a rough waggon, and afterwards in a boat.

Murdock, 1784—1789.—This able assistant of Watt survived him about twenty years, leaving a name intimately associated with Watt's steam-engine in Cornwall, where he was much respected. The eccentric motion and long D slide-valve were his invention, and as a modification of this plan is employed in locomotives, its action will be explained. The hole A in the circular sheave B C D is at some distance from its centre E, which gives it an eccentric motion round the crank shaft A, on which it is fixed. Since A is the centre of motion and E the centre of the sheave, the distance between them is equal in effect to a crank. If that distance is two and a half inches on each side of A during each revolution, the point F of the eccentric strap and rod, B C, D F (fitted so as to move easily round the sheave E), would move five inches, thus converting rotatory into rectilinear motion.

FIG. NO. 100.



Murdock.

For vertical cylinders the levers G, H, fixed on the centre N, connect the eccentric rod with the slide-valve rod *t*, Fig. No. 100. For horizontal cylinders, the connection may be direct, or by intermediate mechanism, as will be shown.

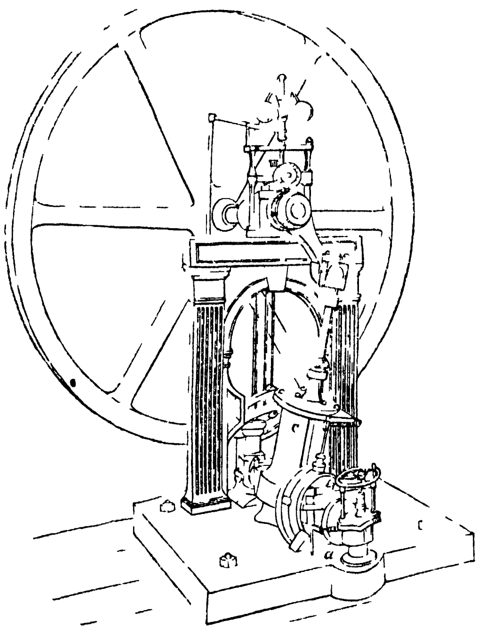
Murdock's rotatory engine consisted of two toothed wheels working in a steam-tight casing, and gearing into each other. The steam enters directly against the teeth then in gear, and forcing them round passes out at the other side to a condenser.

The cylindrical slide-valve, the cylinder boring-bar, and iron cement* for steam-pipe joints, were a few of his contributions to the steam-engine.

He also introduced gas, and the brilliant gas illumination of the Soho works at the Peace of Amiens attracted universal attention, which has led to its present extended and still extending use. A model of an oscillating engine, and also a model of a locomotive engine, both made by Murdock in 1785, were exhibited in the Industrial Palace as the earliest working models of these engines in this country. The locomotive model will be described in the next chapter. The object of the oscillating cylinder C, Fig. 101, is to keep the piston in a line with the angularity of the crank, without a parallel motion or separate connecting-rod. For this purpose the cylinder is suspended on two hollow centres, which serve as steam ports. When the crank is at its greatest angle the cylinder takes the

* This cement was made of sixteen parts cast-iron filings, two parts of muriate of ammonia, and one part of sulphur, mixed together and kept dry till required, when it was made into a paste with water, and calked into the joint. The oxydation cemented the mass into a solid which answers well for such joints.

FIG. No. 101.

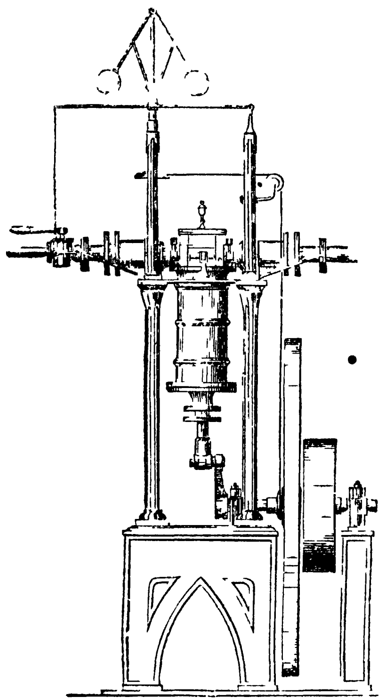


Penn's Oscillating Engine.

same angle, and in like manner at the opposite extreme, or any other part of the revolution. On this principle very compact and good engines are constructed by Messrs. Penn, of Greenwich, one of which is shown, Fig. 101; and also by Napier, of Glasgow, and others.

Messrs. Joyce, of Greenwich, have recently constructed a double-cylinder pendulous oscillating engine of forty-horse power, which is said to be an economical one. The pendulous engine is so called from its cylinder being suspended from its top end on centres like a pendulum, with the piston-rod working out below, as was introduced by Bull in 1790, to evade Watt's patent, although previously used by Cugnot.

FIG. No. 102.



Joyce's Pendulous Engine.

Fig. 102 is a front view of one of Joyce's single-cylinder pendulous engines, showing its simplicity of arrangement and mode of action.

In 1784 M. R. Cameron proposed a rotatory engine, either by a piston moving in a circular channel, or by a piston moving in a lateral path in the cylinder, so that its rod had a screw-like motion forwards as it turned round. He also proposed a long cylinder, divided into two by a transverse central partition, through which the piston-rod worked, and a separate piston in each half. The upper piston was acted on by the atmosphere, and, the lower one by the steam, which was condensed below the piston, and, drawn off by the upper piston in its ascent, caused by a fresh supply of steam.

W. Cook, 1787.—By jointing a series of flaps or pistons of thirty-six square inches area to the circumference of a wheel half inclosed in a steam-tight case, Cook calculated he would have a constant acting force of 531 lbs. on these pistons. The mechanism was so arranged that each piston was closed in a recess in the wheel, as it entered the steam-case, and, opening by its gravity, the steam impelled it onwards, while the casing again closed it to admit its rotation, and so on with each flap or piston.

Patrick Miller, 1787—1796.—This enterprising Scottish gentleman spent about 30,000*l.* in seeking to improve the naval and artillery defences of the nation, yet, like many poor inventors, he was neglected. An equal party expenditure would probably have commanded the attention of the government, for patriotism and political power are two different subjects in most countries. So true is the poet's remark, that—

> "Truths would you teach to save a sinking land,
> All fear, none aid you, and few understand."

The carronade was Mr. Miller's invention; and in naval efforts he constructed some twin and treble-keeled paddle-boats. With two keels, the paddle-wheel worked between the keels; and with three keels, one paddle-wheel on each side of the central keel. The keels were made to work simultaneously by one steersman. With a double-keeled boat a speed of four miles an hour was obtained in the Frith of Forth, by five men working the paddles by a capstan. The boat was sixty feet long and fifteen feet wide.

In these experiments he was actively seconded by his children's tutor, Mr. Taylor, who successfully urged him to employ a steam-engine to turn the paddle-wheels. In 1788 the first trial was made on Dalswinton Lake, in a double pleasure-boat worked by one of Symington's ratchet-motion engines with a four-inch cylinder. With this very small engine a speed of five miles an hour was obtained, which led to a double engine of the same class, with eighteen-inch cylinders, being applied to a boat on the Frith and Clyde Canal in 1789-90, and a speed of seven miles an hour realized. Whether the cost of these trials had exhausted Mr. Miller's resources, and a gentlemanly delicacy prevented his soliciting aid, or other causes operated to induce him to give up his steam-boat experiments when they had thus proved successful, is not known; but from this time he turned his attention principally to agricultural affairs. Mr. Taylor received a pension of 50*l.* per annum from Lord Liverpool; and in 1837 each of his four daughters received 50*l.* as a gift from Lord Melbourne's government, for his aid in introducing steam-boats.

Earl Stanhope, 1790.—As a practitioner in science and art this nobleman holds a high position, regarding it as more honourable to gain an independence as a mechanic than live upon the bounty of friends or on the public purse.

In 1795 he tried a steam-boat moved by paddles, which opened to act against the water, but closed to be drawn through it, like a duck's foot, and with a flat-bottomed boat attained a speed of three miles an hour. R. Fulton, the American steam-boat engineer, showed his lordship drawings of a steam-boat in 1793-4, and it is said urged the advantage of paddle-wheels over the duck-foot oars, but without effect.

François' engine for draining a morass had the water entering the cylinder through a bottom valve by atmospheric pressure, to be expelled by steam from the boiler without any piston. The water to be raised first entered a bucket balanced on a pivot, but with unequally long ends, so that as it filled the long end preponderated and emptied out the water, when it resumed its balanced position again. The alternating motion of the tumbling-bucket was made to open and shut the steam and eduction cocks, somewhat after the plan of Gensanne.

Keupel proposed a rotatory engine by jointing a horizontal tube centrally on the steam pipe, and producing rotation by the emission of steam from small orifices at opposite sides of the tubular arms, as in Hero's ælopile.

Sadler, 1792.—Sadler proposed rotation by steam issuing from similar arms to Keupel's, at great velocity within a case, and renewing the motion by condensing the steam internally, so that the air became the motive power. His reciprocating engine had no beam or parallel motion, but had vertical guides for the piston and air-pump rods to work on by small wheels. The air-pump rod was extended to give motion to a lever pressing the valves and cocks. Although inferior to Watt's, yet, in a competition, the naval authorities preferred Sadler's engine to that of Watt's at that time.

Nuncarrow proposed an ingenious plan of applying a condenser to Savary's engine, for raising water to turn a wheel and drive machinery from this water wheel.

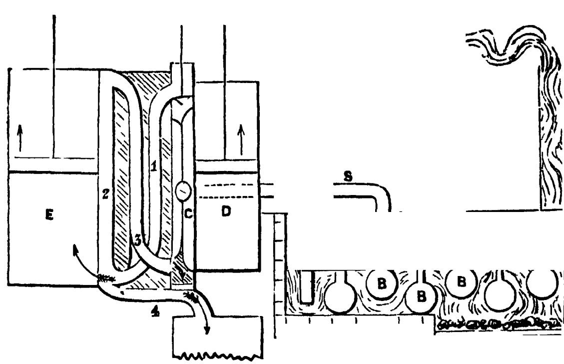
Fenton Murray and Wood, of Leeds, improved the details of the valves, air-pumps, and boilers, along with horizontal cylinders, where most convenient. They also fitted a throttle-valve in the chimney, worked by a small cylinder fitted on the boiler, which partially closed the chimney when the steam was high, but left it open when steam was low in the boiler.

J. Robertson, of Glasgow, proposed a long cylinder with two pistons, that the steam, which usually escaped past the upper piston, might act on the second one, and erected some engines on this plan which worked satisfactorily, until a better class of pistons and cylinders rendered such a plan unnecessary.

At the expiry of Watt's patent, there were only about 1400 horse-power of his engines at work in London, Manchester, and Leeds, so much had prejudice and interest done in retarding the general introduction of this valuable machine.

Woolfe, 1796—1804.—By making Hornblower's engine double-acting, like Watt's, and using higher pressed steam, generated in an improved tubular boiler, Woolfe produced a very efficient class of engines. The boiler A B, fig. No. 103, consisted of six, eight, or more metallic tubes, placed transversely across the fireplace and flues, and connected to a main steam receiving-pipe A, under which a partition wall divided the flue into two. The fire acted directly on the three first tubes, and the products of combustion passed alternately over one tube and below the next until they reached the back of the boiler, when they passed round the end of the partition, and continued their course alternately over and under the tubes until they reached the chimney at the fire end of the boiler. Two half-length steam receiving-pipes were over this part of the transverse pipes, and also connected with the main steam-chamber A, from whence the steam passed by the pipe S to the

Fig. No. 103.



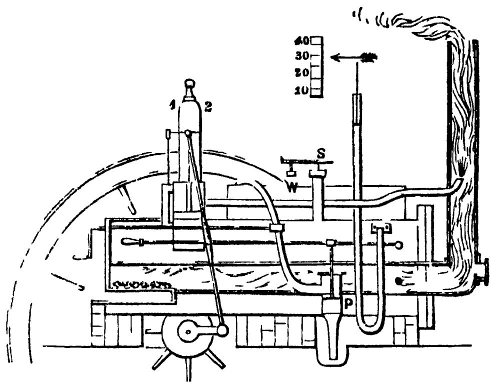
Woolfe.

cylinder steam-chest C, from which the valve V admits it alternately above and below the piston in D, and also alternately from the top of D to the bottom of E, or from the bottom of D to the top of E, by the double connecting passages 1 3. The condenser passage 2 4 communicates with both sides of the piston in E, that it may work in a vacuum. Both the pistons are thus simultaneously moved upwards or downwards at the same time. Sim's engine of this class has the two cylinders on the top of each other, like Cartwright's cylinder and air-pump; but M'Naught places the small cylinder at one end ot the beam, and the larger one near the other end, that they may work at right angles to each other, like two separate engines. Both classes are favourable for efficacy and economy. In these varieties of Hornblower's engine, there is the uniform force of the small piston combined with the decreasing force of the large piston, which gives a more equal mean than is obtained from an equal expansion in one cylinder, although, as has been shown, the total force evolved is greatest for one cylinder.

Trevitheck, 1790—1816.—From 1790 to 1800 this able engineer, in connection with Bull, one of Watt's former workmen, erected several engines with double-acting cylinders on Watt's plan; but to evade his patent, Bull worked the piston-rod through the bottom instead of the top, which on a trial the judges held to be legal.

Trevitheck's acquaintance with Murdock and his models at Redruth led to his celebrated locomotive of 1803, combining the principal features of both models in one engine. Like Evans, Trevitheck preferred high-pressure steam, and his first patent engine had a spherical boiler set in a fire-brick case, with a heating flue all round. The cylinder was fitted into the boiler to maintain its temperature, and a two-way cock, worked by a double eccentric cam on the fly-wheel axle, admitted steam to and from the cylinder. Another plan was to suspend the case, boiler, and cylinder on centres, that the piston might adapt itself to the angularity of the crank; or to suspend the cylinder only, like Murdock's. He afterwards adopted a cast iron boiler, nearly similar in form to Evans', as in Fig. No. 104, where the fire is placed in one end of the central flue, whilst the other end

Fig. No. 104.



Trevitheck, 1800.

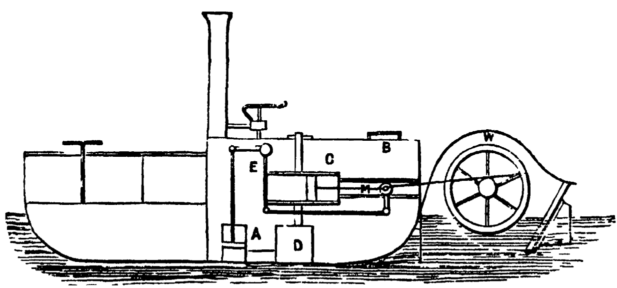
terminates in the chimney. The cylinder is fitted into the boiler, and the fixed guides 1 2 keep the piston-rod in a line with the cylinder. A connecting-rod down each side communicates the piston motion to the cranks and fly-wheel. The exhaust-pipe passed through the cistern W to heat the water for the boiler—also similar to Evans' plan; but Trevitheck's terminated in the chimney, which ultimately led to that important part of a locomotive, the blast pipe. P the cold water pump, M the syphon mercurial gauge, S the steel-yard safety-valve. The boiler pump was on the opposite side.

In 1802 Trevitheck patented a common road locomotive engine, which was successfully tried near London, and on a mineral railway in 1805; but having run off the road it lay in the ditch as if a worthless combination of mechanism. Like Evans', Trevitheck's success was greatest with fixed engines, and after the expiry of Watt's patents, in 1800, he introduced high pressed steam, expanding to a low pressure, with so marked economy that the Court of Spain sent him out with regal honours to drain the silver mines of Peru. The locomotive, neglected by the public, was necessarily neglected by the inventor for the more inviting Spanish commission, which however also ended badly, and Trevitheck returned unrewarded to England, and continued to devote his talents to improve the steam-engine.

Symington, 1786—1804.—In 1786, Symington exhibited a model of a locomotive at Edinburgh, but I have not been able to get any particulars of its arrangement. He also tried to combine Newcomen's atmospheric plan with Watt's separate condenser, yet evade the patent, but failed to do so.

Symington's experience in Scotland with Messrs. Miller and Taylor resulted in his constructing the first paddle-wheel steamboat of the modern class. Supported at the time by Lord

FIG. No. 105.



Symington, 1802.

Dundas, it was called "Charlotte Dundas," after his lordship's daughter. Fig. No. 105 is a diagram of its machinery. The boiler B supplied steam to the horizontal double-acting cylinder C, whose piston-rod is kept parallel by the motion M, and connected by a rod and an outside crank to the paddle-wheel W, to produce rotation in the usual manner. The condenser D and the air-pump A are worked by the cranked lever E, connected to the piston-rod motion. This is a simple and effective plan, which, excepting the condensing apparatus, has been adopted in modern locomotive engines. In 1802 this boat, with a twenty-two-inch cylinder and four-feet stroke, drew two loaded seventy-ton boats, against a strong breeze, at the rate of three and a half miles per hour; but the canal proprietors objected to its use, for fear of the waves injuring the banks. Symington's means were gone, and this efficient steam-boat was laid up in Scotland, near Brainsford, for years exposed to public view—a valuable combination, yet unable to find public support.

When reduced to poverty, and his friends appealed to the government on his behalf, Symington was presented with 100*l.* from the Privy Purse in 1825, and afterwards with 50*l.*!

Cartwright, 1797.—This reverend and talented gentleman patented an ingenious parallel motion, metallic piston, an air-pump, and external condenser. He also proposed a rotatory engine with three pistons and double admission and exit passages for the steam. Power looms, and carriages without horses, were also amongst his plans.

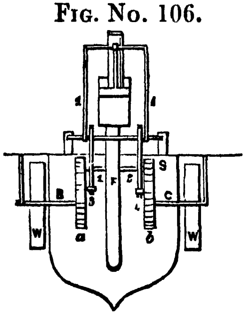
In his reciprocating engine he proposed to use alcoholic vapour, which external condensation did not affect, so that it could be used again and again. His parallel motion was by having two wheels of equal diameter connected to a cross head on the piston rod, and, as the cranks were always opposite to each other, their obliquity was balanced to work the piston-rod vertically. The air-pump was immediately below the cylinder, and both worked by one rod for both pistons.

Hall's patent tubular condenser, as applied to the "British Queen" and other steamers, is an improved form of Cartwright's plan of condensing by external cold. The metallic packing of modern pistons are modifications of Cartwright's piston. In this way the ideas of one inventor are adopted by others in new combinations of greater efficiency.

Fulton, 1793—1807.—This able and persevering man had been long engaged in promoting various plans of steam navigation, and other projects, before he saw the forsaken steam-boat on the Clyde canal. Having visited Scotland, and made himself acquainted with the construction and performances of Symington's neglected steam-boat, Fulton returned to America, and successfully introduced steam-boats on the Hudson between New York and Albany. To Fulton is due the credit of coming to this country and carrying into practice, with the most beneficial results to mankind, a British combination neglected by the British nation. It is a singular, yet melancholy fact, that at the same time the two most remarkable inventions of any age,—practical steam-boats and practical locomotive engines,—were both lying for years as a "reproach" and a "byeword" on the highways of Great Britain,—Symington's steam-boat on the Forth and Clyde Canal, Trevitheck's locomotive engine in a ditch by the road side! Both the inventors died poor, neglected men. America had also her neglected Evans, and France her Cugnot. May we not therefore the more appreciate such men as Boulton, who rescued a Watt from such world-wide difficulties.?

Fulton's first steam-boat, the "Clermont," built in 1807, was 130 feet long, 16½ feet wide, 7 feet deep, and 160 tons burden, worked by one of Watt's double-acting engines, with a vertical cylinder two feet diameter and four feet stroke, connected to the paddle-wheels W W, Fig. No. 106, fifteen feet diameter and four feet broad, by the side levers and outside connecting rods 1, 2, and gearing S *b*. Each paddle-wheel was on a separate axle B, C, having on its inside end a crank 3, 4, for the connecting rod, and a toothed wheel, *a b*, to gear into another on the fly-wheel shaft

FIG. No. 106.



Fulton's Steam-Boat, 1807.

S. As there was only one engine, a large fly-wheel, F, worked in the centre of the boat between the ends of the paddle shafts, to continue the rotation past the dead points of the crank, as shown in the Fig. 106.

American river steam-boats are now celebrated for their size, superior accommodation, number, low fares, and speed, over those of any other nation. On the Hudson, for instance, where steam navigation for hire was first introduced, besides many smaller vessels averaging 200 feet in length, there are upwards of ten floating steam palaces averaging 310 feet length. Two of them are above 1000 tons burden, and many of them travel twenty miles an hour with safety, for explosions are all but unknown on this river. From New York to Albany, about 150 miles, the fare is only 2*s*. 2*d*. in these floating palaces. This is a higher velocity than our parliamentary trains, and at one-fifth the cost to travellers.

Bell, 1800—1812.—In 1800 Mr. Bell fitted a four-horse steam-engine in a small vessel, and sailed from the Clyde to the Thames at the rate, as stated, of seven miles per hour. The extraordinary appearance, it is said, led a sloop of war to give chase in the Bristol channel ; and on an Admiralty inspection in the Thames, considering the invention of no value, Nelson remarked, " Gentlemen, if you do not take advantage of this invention, you may rely on it other nations will." Even this mediation of England's great naval captain failed to secure Bell any better treatment than had been meted out to Savary.

The machinery was taken out and the boat sold. Another application in 1803 shared no better fate, and in 1812 Mr. Bell constructed the " Comet " steam-boat of 25 tons, worked by an engine of about three horse-power, which realized about five miles per hour on the Clyde. As soon as Mr. Bell had overcome popular prejudice and obtained passengers, powerful companies started into existence, which deprived him of any reward for his meritorious exertion and heavy pecuniary sacrifices.

Stevens, 1804.—With a Watt's engine of only four-and-a-half inch cylinder and nine inches stroke, supplied with steam form a boiler consisting of eighty-one horizontal copper tubes, one inch diameter and two feet long, Stevens, of Hoboken, in America, propelled a steam-boat four miles an hour by a screw, on the principle of the smoke-jack vanes. The tubular boiler deserves notice from the number and position of the tubes, being similar to the modern locomotive boiler, excepting that the latter makes the tubes flues, whilst Stevens made them boilers, as was generally done by all common road steam-engines, with steam from 200lbs. to 300lbs. pressure per square inch.

Stevens also constructed one of his boilers six feet long, four feet wide, and two feet deep, with one-inch tubes, to give a heating surface of 400 square feet.

In 1815 Ralph Dodd had a fourteen-horse engine fitted into a seventy-five ton boat, and during a stormy voyage from the Clyde by Loch Ryan, Dublin, Milford, to London, of about 758 nautical miles, run in 122 hours, he clearly showed the power of steam to contend against dangers which would have destroyed sailing vessels.

In 1818 Mr. David Napier successfully prosecuted ocean steam navigation, and in 1822 the "James Watt" of 100 horse-power and 440 tons burden ran from Leith to London, realising a speed of ten miles an hour.

Since that time steam navigation has steadily progressed, and engines with their pistons connected directly to the crank, as in locomotives, without any side levers or beams, are now preferred. Of these direct-action engines the oscillating class are most compact, by also dispensing with the connecting rod, as in Fig. No. 101, made by Penn & Sons, Greenwich.

It may be remarked that rotatory steam-engines introduced by Hero, employed by Branca and Matthesius, have engaged and still engage much attention. The goal aimed at is to obtain from the direct impulse of steam a rotatory motion as uniform as a water wheel, but its economical realization is a difficult problem.

A great variety of rotatory engines have been proposed by Maudsley, Clegg, Chapman, Witty, Ovens, Turner, Routledge, Moore, Congreve, Masterman, and many others of quite recent date, but with limited success.

Amongst the latest is one by Mr. Andrews, of the Great Western Railway locomotive department, combining both Hero's and Branca's plans in a modified form. One of the[illegible] about four-and-a-half feet diameter, with two jets only, was tried at Swindon, which was unfavourably reported of: and it is only fair to give the following good results, handed me by the patentee, as made on a roughly got up five-feet engine, with four jets, and tested by a seven-feet lever Prony's brake, loaded at its extremity :—

Exp. 1st,	Started quickly,			with 140lbs. load
,, 2nd,	Revolv.	84	per min.	with 409lbs. ,,
,, 3rd,	,,	280	,,	with 150lbs. ,,
,, 4th,	,,	3000	,,	without a load.

Steam from eighty to ninety pounds per square inch, was supplied through the hot water steam-pipe of a locomotive boiler standing on the rails at some distance off, and conveyed to the engine by a gas pipe. The inventor expresses great confidence in the result of a fair trial in practice.

The disc and eccentric piston engines are intermediate classes, where a rotatory motion is obtained from the circle described by the piston-rod. Part of the machinery in the Exhibition of all Nations was worked by an eccentric piston rotatory engine, which receives and exhausts steam at two parts of the stroke like a reciprocatory engine, consequently requiring a fly-wheel to continue the motion over the dead points. Whilst genius and experience continue thus directed, they may succeed in solving the problem, but hitherto rotatory engines have failed to compete in economy of power with the expansive reciprocatory engine.

Steam has not attained its eminence without competition; for, besides hot air, gunpowder, gun-cotton, turpentine, alcohol, and explosive gases, have all been tried as sources of motive power, and still occasionally attract notice.

In 1791 R. Street dropped turpentine on hot iron, and exploded the vapour formed below a piston to produce motion.

In 1807 M. De Revaz moved a locomotive carriage by exploding a mixture of hydrogen and air in a cylinder by electricity.

In 1820 the Rev. M. Cecil discussed the comparative merits of steam and an explosive mixture of air and hydrogen, and proposed an engine to be worked by the explosion of air and hydrogen.

In 1823, 1824, Mr. S. Brown constructed a similar, but greatly improved explosive gas engine. Mr. Brunel tried a carbonic acid gas engine; and, modified, these plans have been revived again in America, with other alcoholic gas engines.

Electricity has also been tried somewhat extensively, and both in Great Britain and in America electro-locomotives have realized from six to ten miles per hour with a limited load.

In this fertile field for genius to revel in, it is as yet quite uncertain what treasures may be culled of the motive power class, although at present practically uninviting.

At the last Swindon Mechanics' Soirée were exhibited several models of engines, both by steam and electricity. Amongst the latter was one by James Squires, driving a sectional model of one of the large broad-gauge engines, and another, producing rapid motion, by William Bickle. The latter had two electro-magnetic coils on each side of the centre of two levers, having broad parts immediately over these coils for attraction and repulsion alternately, and their other longer ends were connected to the fly-wheel axis, as in the steam-engine. By a self-acting cut-off valve, for the electric current at opposite angles at the same moment, a double-cylinder action is obtained, which in the small model spun round the fly-wheel with great rapidity.

Squires' plan was by placing the poles of a horse-shoe electro-magnet within the attractive distance of the arms of a fly-wheel, and by a self-acting cut-off produced rotation with considerable power, for the size of the model.*

Ericsson, 1829—1853.—Before closing this historical sketch, the exertions of this enterprising Swedish engineer to introduce hot air as a competitor with steam on the fair field of ocean navigation, require to be noticed, although any remarks now made are liable to be superseded by the results so anxiously looked for by an expectant world.

In England, Ericsson designed the novelty locomotive tried at Rainhill, in 1829; the rotatory-engine steam-boat, tried at Liverpool in 1832-3, with great velocity in the water, but excessive consumption of steam; the hot-air engine, tried in 1834 at Braithwaite and Co.'s, London, with success as a motive power, but failure from friction in the hot cylinder; and his screw-propeller steam-boat of 1837, tried by the Admiralty on the Thames, with much success in public opinion, yet con-

* These models were shown at the conversazione of James Rendel, Esq., President of the Institution of Civil Engineers. London: 1853.

demned by the Admiralty surveyor, and officially ignored at the time.

The American Captain Stockton, however, formed a different opinion; had a larger vessel built at Liverpool in 1838, and sent to America in 1839, where, as the "New Jersey," it plied on the Delaware with success, and screw-propellers are now generally preferred for many purposes.

Since that time Captain Ericsson has been chiefly in America, and has found in B. Kitching, Esq., of New York, a second Boulton, to aid him in testing hot-air power on a truly magnificent scale of operations.

The principle of caloric or hot-air power is heat, the same as in steam or hot-water. In the former air is expanded, and in the latter water is expanded to give out elastic power.

As we have before shown, air is estimated to expand $\frac{1}{480}$th of its bulk for each Fahrenheit's degree of heat added to it; and as its pressure is nearly in the ratio of its volume and space, it follows that by adding 480° of heat to the ordinary air, it would double its volume, or if confined, double its pressure. This would give a total pressure of two atmospheres, and, independent of a vacuum, leave one atmosphere 14·7lbs. per square inch of available power, which inventors seek to apply as a motive power instead of steam.

The difficulties hitherto defeating the success of hot-air power are, the high temperature of about 570° required in the working cylinder, volatilizing or carbonizing any known lubricant, and the excessive friction thereby occasioned.

Perkins experienced the same difficulty with his high-pressure steam, but then he would have at least 33 times the power of air of equal temperature, or upwards of 1000 lbs. per square inch.

The preceding pages have shown that hot-air engines are as old as steam-engines, and that in design they were not surpassed before Newcomen's time, nor yet surpassed by caloric engines as regards heating the air in a separate vessel from the working cylinder. In engines, both rotatory and reciprocatory, Cardan, Branca, Amonton, Leupold, Hautefeuille, and others, have sought to produce an effective hot-air power, or, as in Wilkinson's and Houston's recent patents, by air and steam combined in the same boiler or cylinder.

The obvious safety from explosion, and the lightness of the whole engine, led Sir G. Cayley, in 1804, to propose a hot-air locomotive, which was tried in London, in 1807, before several scientific gentlemen, including the late Mr. Brunel and Mr. Gurney. About 1819-20, Mr. Greenwood had a hot-air engine made and tried at Manchester, with one forcing-in air-pump, and another exhausting air-pump, but the friction led to its disuse.

In 1834 Mr. Stirling had a reciprocatory hot-air engine made by his brother at Dundee, where it worked for several years with much economy of fuel, but, as in others, the friction was a serious drawback to its real utility.

This engine had a wire-gauze absorber of escaping heat, which it restored to the cold air entering through its meshes to the cylinder, and a similar gauze-chamber is an important feature in Ericsson's caloric engine. This gauze reservoir Mr. Stirling called a refrigerator, from its cooling the escaping air; but Captain Ericsson calls it a regenerator, from its heating the entering air.

So far as we can learn, Ericsson's engine is a modification of Sir G. Cayley's and Mr. Stirling's, with his own compact arrangement of the mechanism. We now describe it, to the best of our judgment, as follows: —

The hot-air cylinder, about fourteen feet diameter, has placed at some distance above it the air-supply cylinder, about eleven and a quarter feet diameter, and the open ends of both cylinders facing each other. In the top of the supply cylinder there are two valves, of which one part opens inwards, to admit air, and another part opens outwards, by which to force the air out by the pipe into the airometer. In the bottom is placed a number of thicknesses of wire-gauze, having a surface of many square feet, through which the air passes both to and from the working-cylinder. The slide-valve alternately opens the ports, to admit air to the cylinder, and from it to the atmosphere. The lower part of the working piston is extended downwards, but not fitting the cylinder, that its expansion may not injuriously affect it, whilst it guards the air-tight part of the piston from the direct action of the hot air. The pistons are connected together, which preserves their parallelism, and a bell-crank lever, connected by a link or slot to the main piston-rod, gives motion to the machinery. As the cylinders are only single-acting, it requires four cylinders to give the rotatory power of two double-acting steam cylinders, and they are placed two and two on each side of the paddle-shaft, in lines parallel with the line of the vessel. The connection with the crank-shaft is so arranged, that each pair of acting cylinders work at right angles to each other, as in the double-crank engines.

The action is regulated by the slide-valve, admitting air to the cylinder where it is exposed to the fire, and as it expands by the heat, both pistons are raised simultaneously about six feet high. The large piston gives motion to the machinery, and the small one forces the air to replace that withdrawn from below, and thus balance the supply and demand of air. As the pistons are in an equilibrium of atmospheric pressure on both sides during the downward stroke, their own gravity, aided by the full-power action of the other cylinder, carries them to the bottom ready for another upward stroke again.

At this point the wire-gauze recipient or heat-ometer comes into action, by absorbing heat from the escaping hot air, which is again re-absorbed from the wire-gauze by the cold air passing through it to the cylinder. Its action is precisely similar to that of the respirator worn by invalids or others in cold weather; for in both the human and mechanical arrangement, heat is absorbed by the wire-gauze from the expelled air, and returned to the air which enters through it to the lungs or to the cylinder.

In Ericsson's engine it is stated, that the heat so "caught" in escaping and returned to the cylinder is about 460° out of 510° of added heat to that in ordinary air, and requiring from the fire only about from 50° to 70° to replace that lost by radiation or other causes, and the generation and consumption of caloric or heat is thus adjusted.

In this way the actual consumption of heat is economised to about 25 per cent. of that required for steam; but the amount of friction in passing through the gauze is not as yet publicly known in England, and is highly estimated.

The name of regenerator has been objected to, as implying a creator of power, whilst it is only a recipient of heat, which would otherwise be lost, and perhaps heat-ometer would convey a clearer idea of this important "picker-up" of $\frac{14}{16}$ths of the escaping heat for further duty. If a similar proportion of the 1180° of heat in 30 lbs. steam could be returned to the boiler, the economy of fuel would be very decided, since at most only about $\frac{1}{8}$th of it can be so retained in water heated, by waste or exhausted steam, to the boiling point.

With a practical solution in progress, so much more satisfactory than any theoretical one, it will be unnecessary to discuss the relative expansion of steam or flame and air by heat, since the power of the latter, if safer, is much more confined than that of the former.

The pressure on the supply piston acts against the working piston, at a mean force from zero up to full pressure, about half stroke. In the recent trials a working pressure of 12 lbs.

was said to be realized, and taking 10 lbs. as the full mean pressure on the supply piston, an estimate of the power may be thus arrived at:

	sq. in.		lbs.		lbs.
Area of working cylinder	22167	×	12	=	266004
Area of supply cylinder	14426	×	10	=	144260
Which leaves an available power				=	121744

to move machinery and overcome the friction of the engine, or about equal to 24 lbs. effective steam on an 80-inch piston. The power therefore of Ericsson's two pairs of cylinders, with 6 feet stroke, would be about the same as two 80-inch double-acting cylinders • with a similar stroke, and 24 lbs. high-pressure steam, or 12 lbs. steam in a condensing engine, whose vacuum supplies the other 12 lbs. Double-acting cylinders would however be as valuable to caloric as to steam-engines, which were also single-acting till Watt's time.

The power given out by hot air is, however, variously regarded by the most experienced engineers, who doubt its success, which time will soon solve; but that power is obtained from hot air is quite evident from the example given, less the additional friction of four pistons instead of two in the steam-engine, leaving the air-pumps as equivalent to water-pumps and parallel motion.

From working models of other hot-air engines there appears to be no difficulty in making any number of strokes per minute up to at least 150 or more, but past experience points to friction as the chief obstacle to hot-air engines. Against the disadvantages of friction, unequal expansion of the cylinder, oxydation or leakage, to be overcome by skill and ingenuity, are to be placed the advantages of safety from explosions, economy of fuel and of space,—all considerations of importance in navigation,—and other mechanical operations.

The practical results, therefore, of Ericsson's experiments will be deeply interesting in any point of view; but it will be most satisfactory to learn that he triumphs over those mechanical difficulties which have hitherto retarded the progress of hot-air engines.

Portable Farm-engines.—In the mine, in the factory, on the ocean, and on the rail, steam had produced results of vast importance before its aid was valued by agriculturists. Indeed, its first essay to do the work of horses was resolutely opposed as injurious to their interests; but other opinions now prevail, and steam assists the producers of the staples of food and clothing, as it has long done the manufacturers of metallic, textile, or other products of science and art.

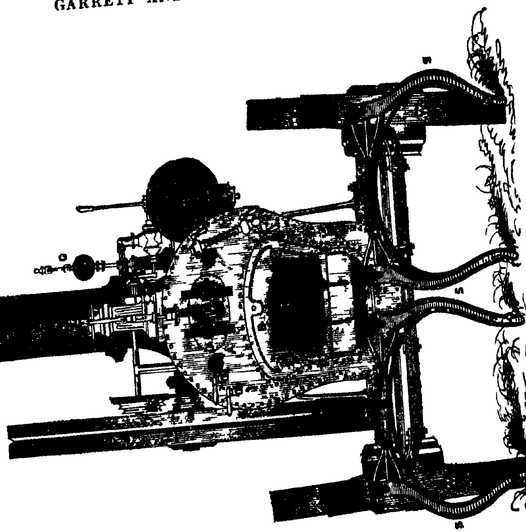
Under the auspices of the Royal Agricultural Society, the farm-engine nearly rivals in economy the factory-engine, although defects, which will be noticed, exist in some of these engines, which can be easily removed.

As a fair example, Messrs. Garrett and Sons' engine was considered by Mr. Carr, of Belper (the Exhibition Jury Reporter of 1851), "the most portable, for its power, of any exhibited" in Hyde Park, which portability is obtained by chiefly using wrought iron in the construction.

Fig. 108 is a fire-box end view, and fig. 109 a smoke-box end view, of this engine. To the fire-box B is fitted the exposed cylinder C, and the parallel motion D is fitted to the boiler A. The fly-wheel H drives the farm machinery, and is connected to the piston by the rod F, whilst the eccentric rod E works the slide-valve. I the water tank, G the governor, H the fire-door, S the shafts, V the safety-valve, W the supporting wheels. The gauges, steam-pipe, and regulator handle are seen on the end views.

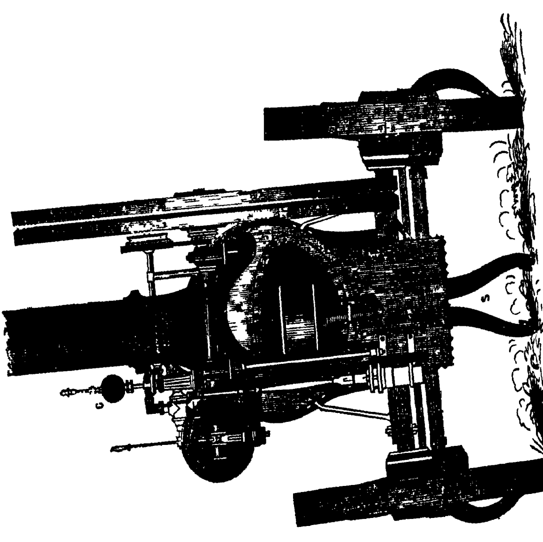
Amongst the farm-engines in the Crystal Palace of 1851 were several of good workmanship, but many of them had exposed cylinders, as if Watt and others had never gained

Fig. No 109.



Fire-box End.

Fig No. 109.



Smoke-box End.

largely by protecting the cylinders from external cold. Practically, the exposed cylinder is a stove as well as a source of power. Steam of 35 lbs. pressure per square inch above the atmosphere, or 50 lbs. total pressure, has a heat of 283°. Now, if a cylinder, or steam pipe, filled with such steam, is surrounded by an atmosphere of 65°, the heat of the steam is rapidly transmitted to the air, and the hands may be warmed at such a cylinder as they might be at any ordinary stove. There is, then, time, heat, and power lost; for it is well known in railway practice that the useful effect decreases with the increase of water in the cylinders, whether there be condensation from ill-protected cylinders or by priming.

The following description of the Exhibition engines, and the dynamic results of these trials, are condensed from the Jury Report of 1851.

General Description of the Engines tried.

Hornsby and Sons.—A horizontal cylinder, fitted centrally in the steam-dome over the fire-box; the boiler covered with dry hair, felt, and wood, and the feed water heated in the smoke-box.

Tuxford and Sons.—No. 1. A vertical cylinder, and the machinery neatly fitted in a case at the end of the boiler, with folding doors to lock up all when required. Their No. 2 engine was similarly constructed, but with an oscillating cylinder.

Clayton and Co.—Neatly arranged, good working engine, with an external horizontal cylinder; now (1853) inclosed in steam.

Garrett and Sons.—Light, strong, portable engines, with an external horizontal cylinder.

Barrett and Co.—External horizontal cylinder, large boiler, and expansive link-valve motion.

Cabron.—Strong heavy engine, with indifferently arranged machinery.

Butlin.—Workmanship moderate, and machinery of simple design.

Burrell.—Machinery simply arranged, and fair workmanship.

Hensman and Son.—The workmanship moderately good, but the boiler too small.

Roe and Co.—Too much cast iron used, with inferior workmanship and arrangements.

PRACTICAL RESULTS OF THE DYNAMIC TRIALS.

Maker.	Horse Power	Time of getting up Steam	Coals used in getting up Steam	Coals used per H. P per Hour	Coals used per Hour of Hornsby's Engine	Coals used per Hour Difference
	No.	Men	lbs.	lbs	Per cent.	Per cent.
Hornsby & Son.	6	19	35 23	6·73	100 0	
Tuxford & Son .	6	53	56·68	7 46	110 8	10·8
Clayton & Co. .	6	32	35 40	8·63	128·2	18 2
Garrett & Sons.	5	42	26·50	8·65	128·5	18·5
Barrett & Co. .	4·5	26	25·56	9 20	136·7	36·7
Tuxford & Son .	4	41·5	35·60	10·85	161 2	61·2
Cabron . . .	9	44	52·00	12·48	185 4	85·4
Burrell . . .	6	28	35·00	13·10	194·6	94 6
Butlin . . .	4·5	50	42 00	14·71	218·4	118 5
Hensman & Son	4	33	29 00	18 75	278·6	178 6
Roe & Co. . .	4	83	75·20	25·8	383·3	283 3

These results were taken by a Prony's brake, on the plan of the Royal Agricultural Society; but it is respectfully suggested that, in addition to the final results, the water evaporated or carried out of the boiler should also be given. The processes of generating and employing steam are, as has been shown, quite distinct, and it would promote the objects of the society to be able to state in their reports whether the discrepancies between engines arose from the boiler or machinery, by simply comparing the evaporative economy with the final economy; for steam once generated, and afterwards condensed before it has left the cylinder, is a great but unseen absorber of steam power.*

The hourly consumption of fuel by these engines follows generally the more or less carefully protected heat, after it is the life of steam.

Thus, Hornsby's well-clad boiler, well-protected cylinder, and hot feed-water, is 10 per cent. more economical than Tuxford's, with the next best protected cylinder; 28 per cent.

* With their steam-surrounded cylinder at Gloucester, in 1853, the coals were only 4·3 lb. per horse-power, which gained the first prize.

more economical than Garrett's or Clayton's, with exposed cylinders; and 36 per cent. superior to Barrett's engine; showing the advantages of well-protected boilers and cylinders, as proved by Clayton & Co , at Gloucester, in 1853.

Steam-Ploughing.—Amongst the first public trials of steam-ploughing was that made by Mr. Heathcote, M.P., on Lochar Moss, at the Scottish Highland Agricultural Society's Dumfries Meeting in 1836; and of late years Lord Willoughby d'Eresby has most commendably persevered to reduce steam ploughing to practice. His engines and implements both admit of improvement, but experience will contribute her counsels and ingraft them on the original plan as on other new fields of enterprise. The present system is to lay down a light portable road at each end of a field, with a portable engine on each road; a chain drum fitted to each engine is worked by the steam, and this chain is connected to the plough, or other instrument, mounted on wheels, and adapted to the soil or duty required. The ploughman regulates the depth of the furrow by levers, and the ploughs are alternately drawn to and from each engine by reversing the motion of the chain off or on the drum. As each set of furrows is completed the engine is moved that distance along the end road, so that the chain may again act in a line with the traction. The comparative economy is stated to be in favour of steam.

As practical examples of this system, the California engine and a plough with four shares and four subsoil prongs were shown at the Exhibition, (No. 195, Class 9,) by Lord Willoughby, but less width of soil acted on at once and greater speed of travelling is now adopted, as lately tested by Prince Albert on his farm at Windsor.

The difficulty of the power moving with the implement is thus obviated, and the question reduced to one of tractive power and portability from field to field. With light engines, capable of using steam of 120 lbs. to 150 lbs. pressure per square inch, as in locomotives, and well-adapted implements to localities, or soils, or duties, Lord Willoughby's system appears capable of extension to many districts, and the engines which now stand idle part of the season may usefully till the land.

A model of a steam plough of a different class was shown by Mr. Usher, of Edinburgh, (No. 123 A, Class 9,) with revolving blades behind the locomotive engine, mounted on wheels. It therefore breaks up or comminutes the soil.

The number of the blades are regulated according to circumstances, and some practical trials of this class of steam ploughs, about six tons weight, have been favourably mentioned in the public journals. In Usher's design the power moves with the implement, but in Lord Willoughby's system the power is stationary during the time of action.

Having shown the practicability of steam ploughing, it is said that Lord Willoughby intends to close these experiments and try steam locomotion on common roads.

The railway locomotive was long regarded as inferior in economy to horses, until, in 1828, Hackworth's Royal George clearly proved the contrary. Yet even Mr. R. Stephenson's experiments on this engine were held, in 1829, to be exceptional by Messrs. Walker and Rastrick, as Lord Willoughby's appear to be generally regarded at present; but, as in the railway case so in the agricultural one, time may develop its progress and a stud of steam horses form a necessary portion of farm stock for field or other work.

In these few pages we have sought to compress an illustrated chronological chart of the principal chiefs, and progress of the steam family, for upwards of 2000 years. Distinguished however as it has become, its founder is unknown in the annals of heraldry. Of its two branches we have just seen how far the rotatory has been left in the rear by the reciprocatory branch, which has performed all the mighty deeds of modern times, by the combined forces of caloric, or heat and water. We may form some faint idea of the anxious hope and fear of each succeeding genius before his conceptions were clothed in mental or material form—the parental grief or joy as each child expired in infancy or arrived at manhood and fame. The scientific knowledge of such men as Desaguliers, Emerson, Smeaton, Black, Robertson and others, were all brought to bear on the progress of the reciprocatory steam-engine. It also embraces the material leading inventions of the loaded safety-valve, piston and cylinder of the ancients; the tubular boiler and steelyard safety-valve of Papin, a French physician; the condensation vacuum and gauge-cocks of Savary, an English miner; of the beam, boiler-pump, injection-pump, and vacuum below the piston of Newcomen, an English blacksmith; the hand-gear of Potter, an English peasant boy; the fly-wheel of Fitzgerald, an Irish professor; the condenser air-pump, double action, parallel motion and governor of Watt, a Scottish mechanic; the crank motion of Pickard, an English mechanic; the metallic piston of Cartwright, an English dissenting clergyman; the oscillatory cylinder, eccentric motion and slide-valve of Murdock, a Scottish mechanic; and the double cylinder of Hornblower, an English mechanic. From these inventors' inventions, modern engineers select at pleasure to construct an efficient engine for the duty to be done.

The first modern engine was Watt's, a Scottish mechanic; the first modern locomotive engine was Trevitheck's, an English mechanic; and the first modern steam-boat was Symington's a Scottish mechanic. The first regular river steam-boat was Fulton's, an American mechanic; the first ocean steam voyage was made by Bell, a Scottish engineer. The most economical engines of the present day are constructed by Cornish mechanics; and the first locomotive was Cugnot's, a French engineer.

The amount of intellectual toil concentrated in a modern reciprocatory engine will therefore be obvious, as also that the principal inventions and combinations are those of working mechanics, who have nearly all died in poverty and distress.

We have now arrived at the locomotive epoch, and under the impression that the preceding outline of the elements of steam, of fuel, and of combustion, with their first-fruits in the garden of industry, will render the path more pleasingly instructive, we now propose to trace out the progress of railway steam locomotion to its present importance and latest forms of engines.

Those who desire a further knowledge of stationary and marine engines, illustrated by elaborate engravings, are referred to Tredgold's third edition of the "Steam Engine," "Pole's Treatise on the Cornish Engine," "Alban's Treatise on High Pressure Engines," "Woodcroft's Treatise on Marine Engines," and "Murray's Rudimentary Marine Engine."

Since 1822, the locomotive power of the reciprocatory steam-engine forms one of the most remarkable events of the age. For ocean locomotion, the varieties of the stationary engine are used, but with their cylinders shortened and of larger diameter to suit the hold of the ships. The beam is replaced by one on each side of the cylinder, connected together by a cross-piece, into which the piston rod is fitted. Oscillating engines are also employed in steam boats, and require less space than beam engines. Boilers are made of such forms as to suit the vessels, but even on land, where space is no object, the forms of boilers have varied and still vary much. Watt's waggon class is losing ground from its weak form. Woolfe's, as improved by Galloway, and Evans', as adopted by Trevitheck and the Cornish engineers, maintain a high reputation. Alban's improved tubular boiler enjoys a good name in Germany, and the locomotive tubular-flued boiler is also used for fixed engines. The railway locomotive engine is self-contained, and takes a form of its own adapted to its special duties, which will be explained and illustrated in the next volume.

END OF VOL. II.

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