CHAPTER V.

PRODUCTION OF MOTION BY COMBUSTION OF POWDER.

THE motion of projectiles is often spoken of as though it were produced instantaneously. Such, however, is not the case; for, brief as may be the period of time occupied in imparting motion to the bullet, its velocity is acquired by a process of gradual development, in much the same way as the speed of the railway train already alluded to; and, in like manner as there are differences in the rate of "getting up speed" in engines constructed for heavy goods trains and those made for the short quick spurts between metropolitan passenger stations, so is the speed attained differently in fire-arms constructed for different purposes and used with powders of different make.

Those powders that evolve their gases slowly, by reason of highness of density or largeness of grain, impart speed slowly to the mass they have to impel; while powders that are small in grain, or light and porous, ignite more rapidly, and, by a quicker evolution of gas, put greater immediate pressure on the projectile, which accordingly is driven at higher speed for the time during which the pressure lasts. Anyone can see, in a small way, the difference of action between fine and coarse powder by casting a pinch or two upon a fire. That of fine grain flashes up briskly the instant it touches the red-hot coals; the large grain goes off comparatively slowly and lazily; while the coarse-grain puntpowders are rather surprising in the length of time they take before they puff off. I have found some of the coarsest grain refuse to ignite by the mere application of a lighted match, just as lumps of coal remain unignited by burning sticks that suffice to inflame the same coal in smaller fragments.

If the greatest amount of impulse from equal quantities of powder were alone to be considered, fine and light-grained powders should give the highest results, especially in the short barrels used for sporting purposes. But there are other matters also to be taken into consideration; not the least of which is danger; and that powder which puts most pressure on the shot will also put the greatest strain upon the barrel, and be more likely than any other to burst the gun.

The amount of force that may be developed by the gases of burning gunpowder is so immense that no ordinary small-arm barrels would withstand the strain if fully exerted. Among a number of experiments carried out at Woolwich, a few years ago, by Capt. Noble and Professor Abel (details of which have been published in the "Philosophical Transactions of the Royal Society"), were a series for the purpose of ascertaining the force of gunpowder when exploded in a closed chamber completely filled by the powder and strong enough to prevent any escape of the gases. Among the powders experimented on was Curtis and Harvey's well-known No. 6; and in this case the pressure was found to be equal to about 42 tons per square inch. In some of the Government powders the pressure was even higher than this.

In a loaded gun, a small portion of the barrel is completely filled with powder; and if this powder, when fired, remained closely confined within that limited space, the gases would develope the pressure of more than 40 tons per square inch, irrespective of the size of the gun or the quantity of powder employed.

It may not unnaturally be asked, if such be the case, how it is that greater results are not obtained from charges of powder less than those generally used. There are, however, several reasons for this. In the first place it must be remembered that, although the powder may fill a given space in a gun, it is not, as a matter of fact, closely confined; for the chamber in which the powder is fired undergoes continued enlargement through the movement of the shot, when once the gases have developed force enough to set the projectile in motion. Thus, 3drs. of powder occupies less than an inch of the barrel in a 12-bore gun; but before the shot leaves the muzzle, the gases have expanded into a space more than thirty times as great as that which the powder originally occupied. Prior to the shot moving from its position, its base, or portion bearing on the powder, forms about $\frac{1}{7}$th of the area on which the gases exert their pressure; but when the shot gets to the other end of the barrel, its base represents less that the $\frac{1}{200}$th part of the area on which the gases press. And this is not all the difference between the powder gases which are able to expand and those which cannot do so. The more closely they are confined, the greater is the pressure they exercise; the greater the pressure, the greater is the heat developed; and the more intense the heat, the more expansive become the gases, and the larger is the amount of force which they exert; so that a repeated action and reaction goes on, increasing the pressure of the pent-up gases, until the whole of the powder is consumed. When, however, relief is given by the movement of the shot, such immense pressure does not ensue; consequently the heat does not become so intense, and accordingly, with less heat, the full expansive force of the gases is not developed.

The heat requisite to ignite the powder is very different from that attained by the confined gases. Black powder ignites at from 500° to 600° Fahr., according to various authorities—the differences of record probably arising from variations in the composition and make of the powder. The gases, however, attain a heat many times greater than that which suffices to ignite the mass, Professor Abel estimating the temperature at 2200° C. (about 4000° Fahr.), in which condition their expansive power would be enormously increased.

When the gases had been cooled down to 0° C. (32° Fahr.), their power of expansion was still sufficiently remarkable, for the "permanent gas" then remaining was found to fill, at ordinary atmospheric pressure, about 280 times the space occupied by the powder before it was ignited. In other words, the cooled gas, while shut up in the chamber in which the powder had been burnt, exerted a pressure 280 times as great as the pressure of the atmosphere; and, as the latter amounts to nearly 15lb. per square inch, the force of the gas would be equivalent to a pressure of about 4200lb. per square inch. And this, be it remembered, was the force of the gas when cold. But the volume of gases is increased with rise of temperature, and that which would occupy one cubic foot of space at 0° C. would fill two cubic feet at 273° C. (nearly 500° Fahr.), and there would be a similar increase for each corresponding rise of temperature; so that the powder-gas which exerts a pressure of 4200lb. when cold, will, when heated to 2200° C., give a pressure of about 38,000lb. or 17 tons to the square inch.

This, however, still falls far short of the 42 tons pressure previously mentioned; but we must not lose sight of the fact that the chamber in which the powder was burnt would not be filled by gases alone. There always is some amount of fouling in the gun after it has been fired, although the greater portion of the solid residue is carried away when the gases make their exit from the muzzle. But when powder is burnt in a closed chamber strong enough to withstand the pressure, the whole of this residue (which, when intensely heated, is in a fluid state) is preserved, and solidifies in the chamber as it cools; and Professor Abel found that the residue amounted to nearly 60 per cent. of the entire weight of the powder originally put into the chamber, and occupied nearly three-fifths of the space. Making, then, due allowance for this, we shall find the pressure brought up to about 6500 atmospheres, or the 42 tons already stated.

It is obvious, therefore (even if we were disposed to allow a considerable margin for possible error), that the charges fired from our sporting guns and other small arms must contain an immense amount of potential force which remains undeveloped under ordinary circumstances. Occasionally, however, by some check on the prompt movement of the projectile, this may be brought into operation, and result in the bursting of a barrel that is strong enough to meet the pressures to which it is usually submitted, but cannot withstand the extra strain which results when the powder gases do not get their accustomed relief. And when anything thus prevents the movement of the shot, small arms doubtless give way long before the maximum pressure is reached, because nothing but the strongest ordnance could possibly withstand the strain; and the gases will always force their way out by the line of least resistance—whether it be by pushing the shot onwards throughout the bore, or by driving a piece out of the weakest part of the barrel.

Under some circumstances, however, when there is no unusual obstruction to the passage of the shot, there appears to be a very peculiar action on the part of quick-burning powder, which gives rise to a much greater pressure than that which is *ordinarily produced* by the very same powder. Possibly this may account for guns occasionally bursting without apparent cause, after many similar charges have been fired with impunity. Messrs. Noble and Abel give some interesting particulars on this point. They explain, in their paper in the "Philosophical Transactions," the means they had adopted to ascertain the amount of pressure produced by different powders. One method was to take the pressure directly by the crusher-gauge, and another was to estimate it indirectly by calculating the amount of force requisite to impart to the projectile the velocity which the chronoscope showed to exist at different points of the barrel as it passed from breech to muzzle. Of course, if a shot of a given weight be moved from a state of rest for one or more inches in a certain fraction of a second, a definite amount of force would be required to effect such movement in that period of time; and if the shot, when in motion, were carried so many inches further in another period of time, the additional speed imparted would also show what amount of pressure must have been exerted in that section of the barrel; and so on throughout the whole length of the bore. In each of these sections the pressure thus estimated would be the mean pressure for the very short space of time during which the shot was passing from point to point, and consequently it would be somewhat less than the maximum pressure exercised. Under ordinary circumstances, however, the two modes of estimation appear to have approximated very closely, but occasionally pressures were set up that were far higher even than those produced by powders closely confined within the space they occupied. Messrs. Noble and Abel make the following remarks on this subject:—

"With powders where a slow and tolerably regular combustion takes place, the maximum tension of the gas, obtained both by direct measurement and by the chronoscope, agrees remarkably closely. There is generally a very slight difference indeed between the indicated pressures; but the case is greatly different where the powder is of a highly explosive or quickly burning description. In such a case, not only are the pressures indicated by the crusher-gauge generally much above those indicated by the chronoscope, but they differ widely in various parts of the powder-chamber, in the same experiment, and even in different parts of the same section of the bore. They are also locally affected by the form of the powder-chamber, and frequently indicate pressures considerably above the normal tensions that would be attained were the powder confined in a close vessel.

It is not difficult to explain these anomalies. When the powder is ignited comparatively slowly and tolerably uniformly, the pressure in the powder-chamber is also uniform, and approximates to that due to the density of the products of combustion. The crusher-gauges then give similar results throughout the powder-chamber, and they accord closely with the results deduced from the chronoscope observations. But when a rapidly lighting or "brisante" powder is used, the products of combustion of the portion first ignited are projected with a very high velocity through the interstices of the charge, or between the charge and the bore; and on meeting with any resistance their *vis viva* is reconverted into pressure, producing the anomalous local pressures to which we have drawn attention.

We have pretty clear proof that, when this intense local action is set up, the gases are in a state of violent disturbance, and that waves of pressure pass backwards and forwards from one end of the charge to the other, the action occasionally lasting the whole time that the shot is in the bore. In fact, with the rapidly burning, and in a less degree even with the slower burning powders, motion is communicated to the projectile not by a steady, gradually decreasing pressure like the expansive action of steam in a cylinder, but by a series of impulses more or less violent.

The time during which these intense local pressures act is of course very minute; but still the existence of the pressures is registered by the crusher-gauges. The chronoscopic records, on the other hand—which are, so to speak, an integration of the infinitesimal impulses communicated to the shot—afford little or no indication of the intensity of the local pressures, but give reliable information as to the *mean* gaseous pressure on the base of the shot.

The two modes of observation are, as we have elsewhere pointed out, complementary one to the other. The chronoscope gives no clue to the existence of the local pressures which the crusher-gauge shows to exist; while, on the other hand, where wave or oscillatory action exists, the results of the crusher-gauge cannot be at all relied on as indicating the mean pressure in the powder-chamber.

An interesting illustration of this distinction was afforded by two consecutive rounds fired from a 10-inch gun, in one of which wave-action was set up, in the other not. In both cases the projectile quitted the gun with the same velocity, and the mean pressure throughout the bore should of course have been the same. The chronoscopic records were, as they ought to be, nearly identical for the two rounds; but the pressures indicated by the crusher-gauge were in the one round (at certain points indicated), respectively 63·4, 41·6, 37·0, 41·9, and 25·8 tons on the square inch; in the other, at the same points, respectively 28·0, 29·8, 30·0, 29·8 and 19·8 tons on the square inch.

Where no wave-action exists, the chronoscopic pressures are generally somewhat higher than those of the crusher-gauge. The difference is not generally greater than about 5 to 7 per cent., although in the case of some exceptionally heavy shot, this variation was considerably exceeded. Among the causes tending to produce this difference may be cited —1. Friction in the parts of the crusher-gauge. 2. Slight diminution of pressure due to the windage. 3. *Vis viva* of particles of the charge and products of combustion, a portion of which would be communicated to the shot, but would not take effect on the crusher-gauge.

On the whole, the accordance of results derived from methods so essentially different was quite as close as could reasonably be expected, and entirely satisfactory."

But besides the extreme amount of force that might possibly be developed under extraordinary circumstances, we have also to consider the variations of force which occur in guns under ordinary circumstances.

If we have gunpowders of the same composition fired in closely-confined chambers, the amount of force developed would be much more than sufficient to burst the barrels of small arms, whether the powder were large or small in grain, or high or low in density; the fact that one powder takes longer to burn than another would not prevent its developing as much ultimate pressure on the confining walls. Such, however, is not the case when the same powders are fired in a gun; for the large and dense grain would burn so slowly that the shot would be gradually pushed on and the chamber considerably enlarged before the bulk of the powder was consumed; and as the development of gas would chiefly take place after the shot had been set in motion, the pressure would not become so intense as when a quick-burning powder gives forth all or nearly all its strength before the shot begins to move.

A small persistent pressure will move an object as well as a much larger and more sudden application of force; but if you apply only a small force, you must continue the pressure for a longer period of time in order to obtain an equal result. Who has not seen an exemplification of this when a railway porter lays his shoulder against a truck several tons in weight and pushes for a while apparently to no purpose? At length, however, the continued pressure begins to tell, and the truck moves, very slowly at first, but gradually getting faster; and eventually the man walks onward with the truck at a tolerably smart pace. He removes the empty vehicle as effectually as an engine that runs against it with a strong bump, and gives a "kick off," which sets the truck running for some distance along the line. The work done by both is the same: the difference is in the time taken to do it, and also, no doubt, in the wear and tear of the machine.

So it is with gunpowders. If you have one that burns very slowly, it will move the shot in course of time, but with a sort of "hang-fire" process, which is immaterial with big guns and sitting shots, but is vexatious to the marksman wishing to hit birds and beasts in motion. If you have a very quick-burning powder, it will set the shot moving in the barrel in less time and with greater rapidity, but also with greater strain upon the breech of the gun; and yet, as the pressure is not maintained to an equal extent throughout the barrel, the shot may possibly leave the muzzle with no higher velocity than that imparted by a slower-burning powder, that gave less strain at first, but kept up its force for a longer time, and so did the same amount of work in the end. In some cases, however, a heavier charge of the coarse powder may be required to give the same velocity as that imparted by the small-grain powder; nevertheless, the small charge of the latter will put most strain upon the gun.

Another example of difference of time in the performance of work is to be found in coal, as compared with gunpowder. As is pointed out by Messrs. Noble and Abel, in their paper in the "Philosophical Transactions," there is more energy in a pound of coal than in a pound of gunpowder. The coal, in fact, will do a greater amount of work than the powder, but takes a longer time to do it. Propositions that have been made for the employment of gunpowder as a motive agent for machinery are therefore futile, though not merely from the difficulties arising out of its explosive character. An explosive mixture of coal-gas and air is employed to work gas-engines, and for some purposes is economical; but the cost of gunpowder is a hundred times as great as that of coal. A large portion of the cost of the powder goes to provide the oxygen requisite for its combustion; whereas, in the case of coal in a furnace, or coal-gas in an engine, an inexhaustible supply of oxygen is drawn, free of cost, from the atmosphere.

The Strain upon the Gun.

No systematic experiments have been carried out to determine the varying degrees of pressure in different parts of the same barrel in sporting guns, but with artillery there have been many such experiments; and those reported to the Secretary of State for War in 1870, by a Committee on Explosives, of which Colonel Younghusband, R.A., was president, afford a very good example of the difference of strain produced by different powders that gave nearly the same amount of velocity to projectiles of equal weight. The powders used were (1) the R.L.G. (rifle large grain), formerly in general use for cannon in our service; (2) the service Pellet powder, of larger grain; (3) Waltham Pebble powder, of still larger grain and higher density; and (4) Russian prismatic powder. They were all tried in the same gun—an 8in. muzzle-loader, with shot weighing 180lb. each; and the barrel was tapped at about twenty places, from breech to muzzle, so as to insert crusher-gauges and cutting plugs, for the purpose of testing the pressure on the breech and different parts of the barrel, and ascertaining, by means of the chronoscope, the velocity of the shot at various points before it reached the muzzle of the gun. Of course the pressures, with such heavy projectiles, are vastly greater than with the bullets used in small arms, but the velocities are not greater, and the pressures will afford a means of comparison between fast and slow-burning powders, which would be very similar in effect to those used in sporting weapons, though in the latter they are on a much smaller scale. The following will show the variations at equal distances of $\frac{1}{10}$th of a foot, or rather more than an inch apart, the first column representing the pressure (in tons per square inch) before the shot moves, and the others showing the rise or fall at subsequent points up to 1ft. from the starting point. The figures 1 to 4 in the first column indicate the four kinds of powder mentioned above.

Pressure in Tons per Square Inch at Points $\frac{1}{10}$ft. apart.

Powder.	1st	2nd	3rd	4th	5th	6th	7th	8th	9th	10th	11th
1	30	19	16½	15½	14½	14	13	12½	12	11½	11
2	2½	13	16½	17½	16½	16	15	14¼	13½	13	12½
3	1	5	11	14	15	15½	15¾	15	14½	14	13¼
4	¼	¾	2	7	20½	19½	17	15½	14½	13¾	13

It will be seen that with the smallest-grained powder (the first on the list) the highest pressure occurred before the shot moved, and then it diminished continuously. With all the others the pressure went on increasing for some inches before it attained its highest point; and the powder which gave its maximum pressure farthest from the breech was the one which put least strain upon the gun. The muzzle velocities imparted by these four powders were—1st, 1324 feet per second; 2nd, 1338; 3rd, 1374; and 4th, 1366. The weight of powder was not equal with the whole of them; those which gave the lowest initial pressures had the heaviest charge—No. 3 having 35lb. and No. 4 32lb., as against 30lb. with each of the other two.

As already stated, the figures in the foregoing table represent the different pressures in the space of 1 foot. From that point the strain gradually diminished throughout the barrel in every instance, so that, 6ft. further on, No. 1 gave only 1 ton pressure; No. 3 was highest, with $1\frac{1}{2}$ tons; and Nos. 2 and 4 nearly equal, at about $1\frac{1}{4}$ tons.

When the projectiles are small, as in sporting rifles, they begin to move under pressures that are very light in comparison with those mentioned above, so that space is quickly afforded for expansion of the gas; and the more readily this relief comes, the less is the advance made towards the 42-ton pressure which would result from an absolute fixture. When the shot moves freely, not only is the gas allowed to pass into a cooler portion of the barrel, but the expansion likewise tends to keep down the heat, and thus limits the force indirectly as well as directly. The heavier the projectile, the greater will be the resistance to the expansion of the quickly-evolved gases, which accordingly will become more heated under the pressure and rendered more expansive by the heat. Hence the danger of using very fine-grained or quick-burning powders with heavy projectiles, and the consequent necessity of making big blocks of slow-burning powder for use with the heavy ordnance of the present day.

How intimately pressure and time are connected will be seen by the following figures, which show the amount of time occupied by the before-mentioned powders in driving the shot the first foot in the barrel—the 12 inches being divided in two spaces of 2in. each and two of 4in. each; and, for the sake of further comparison, times are also given at the two chronograph plugs that were nearest to the muzzle of the gun.

DISTANCES AND TIMES OF EXPERIMENT ON PAGE 85.

Powder	2 inches	4 inches	8 inches	12 inches	6 feet	7ft 4in
1	0005 sec.	·0008 sec.	·0013 sec.	0018 sec.	0058 sec.	·0073 sec.
2	0011 ,,	0016 ,,	0022 ,,	·0027 ,,	·0067 ,,	·0083 ,,
3	·0026 ,	·0033 ,,	·0040 ,,	0045 ,,	·0086 ,,	·0101 ,,
4	·0055 ,,	·0071 ,,	·0080 ,,	0086 ,,	·0126 ,,	·0141 ,,

No. 1, which showed by far the highest pressure in the previous table, also sets the shot in motion much more quickly than the others; but this superiority is very fleeting. At the end of only 12 inches there is already a considerable change of proportion; and for the remaining part of the barrel the times are nearly equal. By taking the relative times at 6ft. and subtracting them from those at 7ft. 4in., it will be found that the speed given by the four powders is almost identical in these 16 inches—the time for this distance being ·0015 sec. with three of them, and ·0016 with the other one. The difference in the total times is, on the contrary, very remarkable, especially with No. 4, which takes about twice as long as No. 1 to drive the shot to the muzzle of the gun; so that, in one sense, it must hang fire to an extraordinary extent. Yet these slow-burning powders make up their leeway before they quit the barrel. At the latest point indicated (7ft. 4ft), Nos. 3 and 4 are already moving quite as fast as Nos. 1 and 2, while No. 3, having left in it the greatest remaining force, is now imparting more velocity than the rest, and will have the highest speed of all at the muzzle.

Effect of Time in Modifying Force.

A very interesting example of the influence of time in modifying the effect of widely-different degrees of force occurred in the course of experiments carried out during the "*Field* Trial of Explosives" at Wimbledon, in 1878. Besides testing samples of black and wood gunpowder with a number of guns at the target, Mr. Walsh, who, as Editor of the *Field,* instituted these trials, endeavoured to ascertain the difference of strain exercised on guns by the various kinds of powder. For this purpose, he devised an apparatus consisting of a strong gunbarrel, fitted with a movable breech-plug, which, being driven back by the firing of the charge, acted on a lever connected with a powerful spring-balance, and registered the effect on the scale of the balance.

This apparatus demonstrated clearly enough that there were very wide divergencies in the amount of force exercised by the different powders, as compared with one another, but no satisfactory formula was forthcoming that would translate the differences on the scale into pounds of pressure. Among the methods tried was one which proved the precursor of the "*Field* force-gauge" (illustrated in the frontispiece, and described in page 36, of the first volume of this work), viz., that of dropping weights from a given height, noting the effects produced on the movable breech-plug and spring-balance, and comparing the results with those obtained by firing charges of powder and shot.

In the course of these experiments it was found that a 7lb. weight, dropped a distance of 1 foot, and transferring its force to the breech-plug, registered on the scale of the balance a very similar effect to that produced by the discharge of 3 drs. of No 6 powder with 1⅛oz. of shot.

Such a result was rather startling, and was received with a good deal of incredulity, until constant repetition showed that it occurred again and again. An opportunity of making a comparison in another way fortunately presented itself, as Messrs. John Hall and Son, the well-known powder manufacturers, placed at the Editor's service a force-gauge they had made for their own use. This was constructed on the same principle as the "crusher-gauges" employed in artillery experiments—copper disks being used, which are compressed by the force of the powder; and, according to the degree of compression undergone by the disk, an estimate is formed of the amount of pressure exercised. By means of this apparatus it had been estimated that 3drs. of coarse-grained powder exerted a pressure of about 2000lb. per square inch on the breech of the 12-bore gun in which it was fired, and that with powder of fine grain the strain was nearly doubled.

The difference between the dropping of a 7lb. weight in the one case and the record of 2000lb. pressure in the other seemed so remarkable, that Mr. Walsh determined to try the direct effect of the falling weight upon the copper disks, and on dropping the 7lb. a distance of 1 foot, as before, the disk was found to be compressed to about the same extent as by firing the charge of 3drs. powder with 1⅛oz. shot. Confirmation was thus given of similarity of pressure on the two gauges; but the difference between the actual weight dropped and the estimated force imparted seemed to be so irreconcilable that it was not unnaturally concluded that "there was something wrong somewhere." The anomaly, however, was more apparent than real, and resulted from *time* being left out of consideration. Allowing for this, the differences are not so irreconcilable as they may appear at first sight.

As in the case of the railway truck recently alluded to (page 83), so with other bodies, motion is imparted by the application of a small or a large amount of force for a long or a short period of time—*the velocity imparted by a given* force being proportionate to the length of time during which the force is applied. On the application of double the force, a given velocity will be acquired in half the time; and any greater increase of force would cause a corresponding reduction of time—resistance from air and friction being for the present disregarded. On the other hand, when a body is in motion, as much power would be required to stop it as was necessary to impart the momentum possessed. If the force applied be the same in both cases, it would take as long to stop it as *to get up equal speed; if stopped in a tenth* or a hundredth part of the time, ten or a hundred times as much force would be requisite.

In the case of the falling weight, we know it would take a quarter of a second to fall a foot; but we do not know what time was taken by the apparatus in stopping the weight which had fallen that distance. But, whereas the weight dropped 12 inches, the breech-plug only recoiled a fraction of an inch. If we knew the exact fraction, we might estimate the time of motion and the consequent resisting force, although the question is complicated by the spring-resistance being an increasing and not a constant pressure. We may be sure, however, that the resistance was considerably greater than the mere 7lb. dropped, or the weight would not have been stopped in less than 12 inches, *i.e.*, the distance which it fell.

Let us see, then, whether we cannot estimate the force that must necessarily be applied to produce the velocity which was imparted to the shot.

There was a charge of 1⅛oz. of shot, which, in the length of a 30in. barrel, had acquired a velocity which we may take to be equal to about 1200 or 1300 feet per second when it reached the muzzle. Starting from the velocity 0 and finishing at, say, 1250, the mean velocity would be 625. And with a mean velocity of 625 ft.-sec. throughout 30 inches, *the time of travel for this 2½ feet would be ·004 sec.* (The pressure is assumed to be equal throughout the barrel, because it not only simplifies the calculation, but shows the lowest strain in the performance of the work; for an unequal force, although it may give the same mean pressure as a constant force, must produce greater strain at some points as well as be under the average at others; and we are here endeavouring to ascertain what is the *least* amount of strain with which the work could be effected).

Now, a falling weight (whether it be an ounce bullet or a ton) would drop 2½ feet in about ·4 sec., or 100 times as long as the shot takes to move up the barrel; the falling weight acquires 12½ foot velocity, and the shot 1250 feet, in moving the same distance. This multiple of 100 happens also to fall in very conveniently with other parts of the calculation. To give to 1⅛oz. of shot 100 times the velocity attainable in a drop lasting ·4 sec., would require a pressure equal to 100 times the weight of the shot to be kept up for an equal period of time. Now, 100 times 1⅛oz. amount to 7lb.; and a pressure of 7lb. continued for ·4 sec. would give the 1250 feet muzzle velocity, or a mean speed of 625 feet. But in ·4 sec., at that mean speed, the shot would move 250 feet, and the barrel of your gun is only 2½ feet long. Therefore, to compensate for this difference between 250 and 2½ feet, you must lessen the time to a corresponding extent, *i.e.*, reduce it to its 100th part, or ·004 sec.; and, in order to effect this, the pressure must be increased 100 times more, making it equal altogether to 10,000 times the weight of the shot. Thus we get to a pressure of 700lb. as the force requisite to impart 1250 feet velocity to 1⅛oz. of shot in a 30in. barrel; and as the area of a 12-bore is only about four-tenths (·417) of a square inch, the 700lb. applied to that area would be equal to a pressure of more than 1700lb. on the square inch.

It may be remarked that in the foregoing observations reference is made to an assumed drop of $2\frac{1}{2}$ feet, whereas the actual fall was only 1 foot. It must be remembered, however, that if the barrel had been cut down to a foot in length, the pressure on the breech would not have been diminished; although the velocity of the shot would necessarily be less, in consequence of the force having operated for a shorter period of time. Supposing the force to be constant, the shot that attains 800 feet velocity in a 12in. barrel would have 1250 feet velocity at 30in. And a corresponding result occurs with the falling weight—it acquires 8 feet velocity in 12in., and about $12\frac{1}{2}$ feet velocity in a 30in. drop; but it is a constant pressure of 7lb. for either distance, though in operation in the one case for longer time than in the other, and consequently producing higher speed.

The momentum is alike in both the above-mentioned cases. If a 7lb. weight is dropped a distance of 1 foot, the constant force of gravity imparts 8 feet velocity in $\frac{1}{4}$ second (·25 sec.) and 8 times 7lb. produce 56 units of momentum, or "force pounds" (to adopt an expression coined by Mr. Walsh when writing on this subject). If, on the other hand, $1\frac{1}{8}$oz. of shot be propelled 1 foot in a gun-barrel under a constant pressure of 700lb., it will attain 800 feet velocity in $\frac{1}{400}$ second (·0025 sec.); and 800 times $1\frac{1}{8}$oz. are also equal to 56 units of momentum or "force pounds." But the record on the scale of the spring balance did not represent the pounds of pressure in either case; it merely demonstrated that the pressure of a small weight acting for a comparatively long time produced a similar effect to that caused by a much higher pressure acting for a much shorter time; and an examination of the scale neither showed how high was the pressure nor how short the time.

The 700lb. pressure required to produce the velocity above stated would be *the smallest amount of force by which the work could be done*—without making any allowance whatever for friction, or for air-resistance in the barrel, both of which would add considerably to the work to be performed; nor has any allowance been made for diminished force in the gas, which would give much greater pressure at the breech than it would near the muzzle. Taking these matters into consideration, we may fairly assume that there would be a large increment on the 1700lb. pressure, and that the 2000lb. indicated by the copper disk would, after all, not be anyway over the mark. In short, there was, practically speaking, no discrepancy between the results obtained from the falling weight and those shown by the crusher-gauge.

Supposing the attempt were made to impart velocity to very heavy projectiles in the same brief space of time as with those of light weight, it will be seen what enormous force would be required to effect it. But, with increase of weight in shot, it is requisite to make use of slower-burning powder, which does not impart speed so rapidly, but keeps up the pressure for a longer period of time, and requires a longer barrel to enable it to impart the required velocity; and the lower pressure, exerted for a longer time, produces equal speed with less strain on the gun. If we apply the foregoing mode of computation to the 180lb. shot used in the artillery experiments already alluded to (page 85), we find that, owing to the longer period of time during which the pressure acts in a 9ft. gun, a comparatively smaller amount of force is required, and that, instead of its necessitating a pressure equal to 10,000 times the weight of the projectile, 3600 times would suffice. The pressure would thus amount to nearly 290 tons, which would be the constant force requisite to impart the velocity the projectile attained in the gun; but the area of the base of the shot was about 50 square inches, so that the required pressure per square inch would be rather less than 6 tons. This, it will be seen, was far below the maximum strain given by any of the four powders used in the experiment; their pressure was variable, and not a constant force, and, while the maximum pressure was greatly above 6 tons near the breech, the minimum was only about 1 ton near the muzzle. We may therefore assume that, if a constant force of 700lb. (equal to about 1700lb. per square inch) were required to perform the work done in a 12-bore gun, the maximum pressure near the breech would also be considerably higher in the shoulder gun as well as the cannon. But we could not ascertain the exact amount of variation in different sporting guns, and with different powders, unless recourse were had to a long series of experiments similar to those carried out with artillery on behalf of the Government.

Increasing Weight of Bullet.

Every increase in weight of projectile with the same charge of powder virtually lengthens the period of time before the shot begins to move, and thus enables greater force to be developed in the powder gases; but an increase in weight of powder (the projectile remaining as before) does not increase the velocity in anything like the same proportion. Thus, a 12-bore rifle by Holland was shot with spherical ball, with charges of 4drs., 5drs., 6drs., and 7drs. of Curtis and Harvey's No. 6 powder, and, the velocities having been ascertained by chronograph, the following table will show the per-centage of increase in initial velocity as compared with increase of powder:

Charge of Powder.	Muzzle Velocity
4drs.	1230 ft. per second.
5drs., or increase of 25 per cent.	1355 f.-s., or increase of $11\frac{1}{3}$ per cent.
6drs., or increase of 50 per cent.	1492 f.-s., or increase of 21 per cent.
7drs., or increase of 75 per cent.	1594 f.-s., or increase of 29 per cent.

It is not to be expected, however, that the velocity should increase in direct proportion to the increase of powder; for the amount of "energy" in the bullet is proportionate to the square of the velocity, and if the energy imparted to the bullet were increased in proportion to the amount of powder, the velocity would be only proportionate to the square-root of the respective charges. On this principle a formula was framed many years ago, by whom is not stated, but it is said to have been based on actual experiment, and was thus laid down in Cape's "Course of Mathematics," a work written for the use of Students at the East India Company's Military College, Addiscombe:—"Divide three times the weight of the powder by the weight of the shot, both in the same denomination. Extract the square root of the quotient. *Multiply* that root by 1600, and the product will be the velocity in feet." This formula gives the initial velocity of spherical balls with approximate correctness in many cases; but it is not strictly accurate with increasing charges and the same bullet, as will be seen by the following figures, which place in comparison the before-mentioned 12-bore velocities as ascertained by means of the chronograph, and the corresponding numbers calculated from the above formula:

Powder.	Chronograph	Formula.
4drs.	1230 ft sec.	1157 ft. sec.
5drs.	1355 ,,	1324 ,,
6drs.	1492 ,,	1450 ,,
7drs.	1584 ,,	1566 ,,

Here it will be observed that the velocities ascertained by the chronograph are always higher than those calculated by the formula; but the difference with the 4drs. charge is four times as great as with that of 7drs., thus showing a greater proportionate amount of energy developed in the small charge than in the large one. The reason why small charges of powder have greater proportionate energy than large ones used in the same gun, and with the same bullet, is a matter which will come into consideration further on.

When the bullet alone is increased in weight, and the powder remains stationary, the effect is the reverse of that just mentioned. The velocity is decreased, as might be anticipated, but not in a proportionate degree with the difference in weight of lead; and the heavier the bullet, the greater is the amount of energy imparted. The following figures will show the difference in velocity and energy of bullets of 280grs. and 365grs., fired with the same charge of powder ($4\frac{1}{4}$drs.) from a ·450-bore rifle by Rigby:

Bullet of 280 Grs	Velocity.	Energy	Bullet of 365 Grs	Velocity	Energy
At Muzzle	1825 ft.-sec.	2082 ft.-lb	At Muzzle	1700 ft.-sec.	2355 ft.-lb.
„ 50 yds.	1640 „	1681 „	„ 50 yds.	1564 „	1993 „
„ 100 „	1470 „	1350 „	„ 100 „	1436 „	1680 „
„ 150 „	1316 „	1082 „	„ 150 „	1320 „	1420 „
„ 200 „	1186 „	879 „	„ 200 „	1218 „	1209 „
„ 300 „	1011 „	639 „	„ 300 „	1059 „	914 „

Thus, the charge of powder being the same, but the weight of lead raised from 280 to 365 grains (an increase of 30 per cent.) the muzzle velocity fell off barely 8 per cent. Yet, notwithstanding that the heavy bullet had least velocity, it had most "energy," for, under the influence of the increased resistance, the powder had imparted 13 per cent. more working-power. If the force of the powder were a constant quantity, the energy of the two bullets would be alike; but, in order for them to be equal in energy, the muzzle velocity of the lighter bullet would have to be 1940 instead of only 1825 feet per second; and even then such would only be its energy at the muzzle of the rifle.

After the projectiles have left the barrel, the greater power resulting from increased weight is more fully demonstrated. At 150 yards the above heavy bullet has the superiority even in point of speed, while its energy is now about 30 per cent. higher; and the greater comparative loss of velocity and energy by the light bullet becomes more and more marked as the distance increases.

Some examples of a similar character with Holland rifles of larger bore may also be worth quoting.

	Velocity	Energy
·500-bore, with 381grs. bullet and 4drs	1666 ft.-sec.	2364 ft.-lb., or 591 per dram.
·500-bore, with 381grs. bullet and 5drs.	1749 ft.-sec.	2605 ft.-lb. or 521 per dram.

Increase of powder, 25 per cent.; increase of velocity, 5 per cent.; increase of energy, 10 per cent.; but, dram for dram, about 12 per cent. less work was done by the heavier charge.

	Velocity	Energy
·577-bore, with 502grs. bullet and 5drs	1616 ft.-sec.	2926 ft.-lb., or 585 per dram.
·577-bore, with 502grs bullet and 6drs	1739 ft.-sec.	3389 ft.-lb., or 565 per dram.

The powder was increased by 20 per cent.; but the velocity was only increased 8 per cent., and the energy 16 per cent. by the larger charge of powder; and, taking dram for dram, nearly 4 per cent. less work was done by the larger charge.

On the other hand, the same charge of powder (6drs.) was used with ·577-bore bullets of three different weights, viz., 459 (hollow), 502, and 648grs. with the following results:

	Velocity	Energy
6drs. with 459grs (hollow)	1723 ft.-sec.	3038 ft.-lb., or 506 per dram.
6drs. with 502grs. (solid)...	1739 ft.-sec.	3389 ft.-lb., or 565 per dram.
6drs. with 648grs. (solid) .	1603 ft.-sec.	3716 ft.-lb., or 619 per dram.

The heaviest bullet showed 25 per cent. more energy than the lightest bullet, and 10 per cent. more than that of medium weight, though the powder was alike with each.

It appears to be clear, too, that if additional resistance is offered to the powder-gases by the cartridge-cases being very greatly turned over when the shells are made of paper, or very tightly crimped in when they are made of brass, the shot does not start so quickly, and a much higher degree of force is developed in the powder, with a corresponding strain upon the breech. Moreover, in all these matters that produce increased energy on the part of the powder, there is the fact to be considered that they also affect the recoil, and are likely to produce an amount of muzzle-disturbance that may considerably affect the accuracy of aim.

WEIGHTS OF POWDER AND BALLS.

It may perhaps be of service to insert here a comparative list of drams and ounces, with the corresponding number of grains, as it frequently happens that weights of powder and shot are given with different nomenclatures, and it is not *easy under such circumstances to estimate the proportion* between the one and the other, seeing that neither the dram nor the ounce consists of even grains. Occasionally, too, people are confused by the difference between the avoirdupois and the apothecaries' dram; so it may be as well to say that the latter is not used for weighing gunpowder, and is more than double the weight of the former. The avoirdupois dram, which is the one always used, is the $\frac{1}{256}$th part of a pound, or the $\frac{1}{16}$th of an ounce; consequently the dram is a small fraction over $27\frac{1}{3}$ grains (27·34375). It may be useful, too, to foreign readers to say that a "gramme" is equal to about $15\frac{1}{2}$ grains (15·432); and that 1·77185 grammes equal a dram. It should be understood, however, that the miscalled "drams" of Schultze or E.C. powder are not drams at all. Like the pound, the dram is a weight, not a measure; and although a measure may be made to hold a dram or a pound of one substance, it will not hold an equal weight of all others. A 1lb. tin made for black gunpowder will only contain about half a pound of Schultze or E.C., for these explosives are only half as heavy as black powder. Yet many people make use of a measure intended for 3drs. of black powder, and on filling it with one of the nitro-compounds, say that they shoot with 3drs. of Schultze or E.C., whereas in reality they are only using about $1\frac{1}{2}$drs.

Comparison of bullets may also be facilitated in some cases if the weight of spherical balls is appended; and they are therefore given in a third column.

Powder Weights.		Shot Weights.		Weight of Spherical Balls.	
Drams.	Grains.	Ounces.	Grains.	Bore and Diameter.	Grains.
0¼	7	0⅛	55	4-bore (1·052in.)	1750
0½	14	0¼	109	6-bore (·919in.)	1166
0¾	20½	0⅜	164	8-bore (·835in.)	875
1	27⅓	0½	219	10-bore (·775in.)	700
2	55	0⅝	273	11-bore (·751in.)	636
3	82	0¾	328	12-bore (·729in.)	583
4	109	0⅞	383	14-bore (·693in.)	500
5	137	1	437½	16-bore (·662in.)	437½
6	164	1⅛	492	18-bore (·637in.)	388
7	191	1¼	547	20-bore (·615in.)	350
8	219	1⅜	602	24-bore (·579in.)	292
9	246	1½	656	28-bore (·550in.)	250
10	273	1¾	766	30-bore (·537in.)	233
11	301	2	875	32-bore (·526in.)	219
12	328	4	1750	36-bore (·506in.)	194
13	355	6	2625	40-bore (·488in.)	175
14	383	8	3500	44-bore (·473in.)	159
15	410	12	5250	48-bore (·459in.)	146
16, or 1oz.	437½	16, or 1lb..	7000	50-bore (·453in.)	140

By comparing the figures relative to the 4-bore and 32-bore, it will be seen that the latter is one half the diameter and one-eighth the weight of the former; the 4-bore bullet weighing $\frac{1}{4}$lb., and the 32-bore $\frac{1}{32}$lb. or half an ounce. In like manner may be found the weight and diameter of other spherical balls, as the 40-bore will enable us to ascertain that the 5-bore would be ·976in. diameter and weigh 1400grs.; and from the 10-bore we may find that the 80-bore ball would weigh 87 grains, and be ·387in. diameter. Of course this pre-supposes that the bullets are of lead throughout, and the bore of the gun is accurate, as in some cases hardened alloys are used instead of pure lead, and in others the bore is not strictly what it is represented to be.

WORK DONE BY THE POWDER.

There are several ways in which the amount of work obtainable from the consumption of powder may be regarded. Some persons are anxious to obtain an exceedingly high velocity, regardless of the quantity of powder they may consume; others may look at the comparative amount of work obtained from a given charge of powder, and think they get a better return by the use of a larger weight of lead with less proportion of powder.

It appears to be beyond question that the more you increase the quantity of powder in a gun, with the same projectile, the less proportionate return you get for it in the way of work done, although you may make some addition to the muzzle velocity; and, on the other hand, the more you add to the weight of the projectile, the greater the amount of work you obtain, although there may be some loss of muzzle velocity. A few remarks on this point have already been made; but here will be found grouped together a number of records of experiments with rifles where the velocities of the bullets have been ascertained by chronograph. The details from which these particulars are collected together, have for the most part appeared in the *Field* during the last three or four years; but it has not been thought necessary to recapitulate all the circumstances connected with them, nor to give the names of the makers of the respective weapons. The purpose here is not to draw comparisons between the rifles of different makers, or to show that one gave a higher velocity or did a greater amount of work than another, but rather to point out that the same principles apply to the whole of them, although there may be certain differences of detail. In order, however, to identify the different weapons, and so make references from one to another, a distinctive letter has been applied to each;

and where the same rifle has been used several times in succession, with differences in weight of powder or lead, the same letters are repeated with a suffix, as "G A," "G B," &c. The first tables, besides giving the length of barrel and charge, will show the proportion of powder to lead, the muzzle velocity obtained, and the consequent "energy," or amount of work, produced by each dram of powder. This energy, be it observed, is the amount that exists when the projectile quits the rifle; and at the end of 100 or 150 yards the heavy bullets will retain a much larger proportion than the light ones.

VELOCITY AND ENERGY OF EXPRESS RIFLES.

Rifle.	Barrel.	Charge of Powder.	Weight of Bullet	Proportion of Powder to Lead.	Muzzle Velocity	Energy.	
						Total.	per drm.
	·400 BORE.				ft. per sec.	ft.-lb.	ft.-lb.
A	26in.	3drs.	209grs.	1 to 2·55	1874	1628	543
	·450 BORE.						
B	26in.	5½drs.	274grs.	1 to 1·82	2000	2431	442
C	28in.	4drs.	275grs.	1 to 2·50	1901	2218	554
D A	26in.	4¼drs.	280grs.	1 to 2·41	1825	2082	490
D B	same.	same.	365 ,,	1 to 3·14	1695	2340	550
E	26in.	4drs.	322grs.	1 to 2·93	1776	2254	564
F	33 3/16 ,,	3⅜drs.	480grs.	1 to 5·64	1315	1841	595
	·500 BORE.						
G A	26in.	4drs.	381½grs.	1 to 3·49	1666	2364	591
G B	same.	5 ,,	same.	1 to 2·85	1750	2605	521
G C	same.	4¼ ,,	*339 ,,	1 to 2·92	1699	2184	514
H	28in.	5drs.	342grs.	1 to 2·40	1946	2872	574
I	28in.	5drs.	444grs.	1 to 3·22	1784	3154	631
	·577 BORE.						
J A	26in.	5drs.	502grs.	1 to 3·67	1616	2926	585
J B	same.	6 ,,	same.	1 to 3·06	1739	3389	565
J C	same.	same.	*458½ ,,	1 to 2·80	1723	3038	506
J D	same.	same.	†287¼ ,,	1 to 1·14	‡1900	2315	386
K	26in.	6drs.	591grs.	1 to 3·60	1663	3648	608
L	28in.	6drs.	648grs.	1 to 3·95	1603	3716	619
M	28in.	7drs.	710grs.	1 to 3·72	1730	4743	678

* Hollow bullets. † Spherical. ‡ Estimated velocity.

It will be observed, from the above figures relative to Express rifles, that where the same charge of powder is used, but the weight of the bullet is increased, there is nearly always a greater development of energy, whether the same rifle is used or one of different bore. For facility of reference, let us group together those where the charges of powder are equal but the bullets vary in weight, and then compare the energy given by them respectively.

4 Drams.		Ft.-lb.	4¼ Drams.		Ft.-lb.
(C)	275 grs.	2218	(D A)	280grs.	2082
(E)	322 grs.	2254	(G C)	*339grs.	2184
(G A)	381½grs.	2364	(D B)	365grs.	2340
5 Drams.		**Ft.-lb.**	**6 Drams.**		**Ft.-lb.**
(G B)	381½grs.	2605	(J C)	*458½grs.........	3038
(H)	342 grs.	2872	(J B)	502 grs...	3389
(I)	444 grs.	3154	(K)	591 grs.............	3648
(J A)	502 grs.	2926	(L)	648 grs.............	3716

Except in one instance, the number of foot-pounds of work increases with the increased weight of the bullet. The exception occurs with the 502gr. bullet used with 5drs. of powder (J A), which gives a lower result than the 444gr. (I) with the same quantity of powder; but the latter was a rather heavy bullet of ·500 bore, and the former a rather light bullet of ·577, and the smaller-bored rifle was 2in. longer than the other.

There are but two instances in which hollow bullets were used, and these are marked with an asterisk (*). In that fired with 6drs. of powder (J C) a much lower result is shown than was obtained with the solid bullet (J B) shot with the same rifle. In the other instance, the hollow bullet (G C) was of ·500 bore and heavier than the ·450 solid bullet used with the same charge of powder. Here the higher weight gave the best result, as usual; nevertheless, that result was inferior to what was obtained with a solid bullet (E) which had a similar proportion of powder to lead, although the charge was but 4drs. It is to be regretted that there is not more available evidence about hollow bullets. We must be cautious not to draw too strong conclusions from so small a number of examples; but, as far as these go, it would appear not only that hollow bullets show a less amount of energy than solid bullets of equal size and consequently greater weight, but that they also give lower results than solid bullets of the same weight. And such seems to be only what we ought to expect; because hollow bullets must be longer than solid bullets of equal weight, and therefore would take greater hold on the rifling; and the increased amount of friction of the elongated hollow projectile would be likely to lessen its muzzle velocity, as compared with that of the shorter solid bullet. Nevertheless, we must not assume that the case is proved, for the velocities of the solid and the hollow bullets were taken on different days, and there may have been sufficient change in atmospheric conditions to account for the result if all the facts were known.

VELOCITY AND ENERGY OF LARGE-BORES.

Rifle	Barrel.	Charge of *Powder*	Weight of *Bullet*	Proportion of Powder *to Lead*	Muzzle Velocity	*Energy.*	
						Total	per drm.
	12 BORE				ft. per sec.	ft.-lb	ft.-lb.
N A	26in.	4drs.	599¼grs.	1 to 5·12	1230	2024	506
N B	same	5 ,,	same	1 to 4·09	1355	2456	491
N C	same	6 ,,	same	1 to 3·41	1492	2978	496
N D	same	7 ,,	same	1 to 2 90	1584	3356	479
	10 BORE.						
O	26in.	8drs.	689¼grs.	1 to 3·15	1557	3700	463
P	*28in.	same	same	same.	1567	3778	472
Q	*25¾in.	5drs.	698grs.	1 to 5·11	1316	2681	536
	8 BORE.						
R A	24in.	9drs.	875grs.	1 to 3 56	1479	4272	475
R B	same	10 ,,	same	1 to 3·20	1541	4638	464
R C	same	§10drs.	same	same.	1346	3539	354
S A	26in.	10drs.	862grs.	1 to 3·15	1654	5232	523
S B	same	same	†1257 ,,	1 to 4·59	1500	6273	627
	4 BORE.						
T	24in.	14drs.	1257½grs.	1 to 3·28	1581	7016	501
U A	25⅛in.	‡12drs.	1250grs.	1 to 3·81	1460	5912	493
U B	same	same	†1822 ,,	1 to 5·73	1330	7387	616

* Smooth bores. † Conical bullets. ‡ No. 7 grain powder. § No. 8 grain.

Spherical balls do not afford the same opportunities for comparison as elongated projectiles, because bullets of the same bore must be pretty nearly of the same weight, as the differences would mainly arise from the specific gravity of the metal, which in some cases may be of lead and in others consist of an alloy of lead with tin or some other metal. In two cases, however, in the foregoing table, viz., in the 4-bores and 8-bores, are instances of the same rifle being shot with conical as well as spherical bullets. The difference in energy of the two kinds of bullets, with equal charges of powder, is remarkable.

Comparing the figures, we find that where (as with rifles N and R), different charges of powder are used with bullets of the same size, the highest charges give comparatively the lowest results. There is a slight divergency between NB and NC, but it is so small as to be unimportant. Where the same charge of powder is used for spherical balls of different size (as NB and Q), the heaviest shows the greatest energy. SA gives a higher result than RB, although the bullet is a trifle lighter; but rifle S is two inches longer than rifle R, and so is enabled to do more work with the same charge of powder. It does not necessarily follow that the powder is unburnt in the short barrel. All may be consumed; but the nearer it is burnt to the muzzle, the less amount of work is got out of it. We therefore usually find that the small-grain powders, which are burnt almost before the projectile is set in motion, produce the greatest amount of energy, although this advantage may be counterbalanced by serious disadvantages, not the least of which is the great strain put upon the barrel. *On the other hand, instances do occur in which* the powder is not all burnt; and such was possibly the case with RC. The same quantity of powder (10drs.) was used as with RB; but the latter was C. & H. No. 6, and the former C. & H. No. 8. The barrel was only 24in. long, and the coarse-grained No. 8 gave but 354 ft.-lb. per dram, as against *464 ft.-lb. with No. 6. In the 4-bores there is a somewhat* similar instance, but less in degree. U A, with longer barrel than T, and smaller charge of powder, should give a greater amount of energy per dram; but T used No. 6 grain powder, whereas that of U A was No. 7. The strain was less with the latter, no doubt; but, being a slower-burning powder, it did a less amount of work, even if it were all burnt. In all cases, except those just mentioned, it is believed that the powder used was No. 6.

Attention has already been called to the remarkable development of energy with the conical bullets S B and U B, as compared with the spherical balls S A and U A; but it may be remarked, as another illustration of what has been said before, that with neither conical nor spherical bullet did rifle U give so high a result per dram as S. Looking at the charges and the bores, the reverse might be expected; but U was shot with No. 7 and S with No. 6.

One other matter may perhaps be worth mention, and that is with respect to the difference of result, small though it be, between O and P. These, it will be seen, were shot with exactly the same charge and bullet, but the former was a rifle and the latter a smooth-bore. The smooth-bore gave a few feet higher velocity; but it must not necessarily be assumed that this was due solely to the difference of friction in the two barrels. The smooth-bore was two inches longer than the rifle, and thus would have an advantage; and it is possible that, if they had been of equal length, the greater initial resistance in the rifled barrel would develop in the powder an additional amount of force that might more than compensate for the loss by friction. At all events, the subject is one on which it would be interesting to have additional evidence.

Effect of Length of Barrel on the Work done by Powder.

Several brief allusions have already been made to the difference of length of barrel and its influence on the amount of work done by the powder. The information afforded by the experiments summarized in the preceding tables may also be turned to account in illustration of the effect produced by barrels of different length in varying the amount of work done by equal charges of powder in guns of the same calibre. In Messrs. Noble and Abel's papers in the "Philosophical Transactions," the subject is elaborately gone into as regards artillery; and by utilizing the results of their labours, and adapting great things to small, we possibly may extract from the before-mentioned experiments with sporting rifles something serviceable as well as interesting.

It would occupy too much space here to give the full details leading up to Messrs. Noble and Abel's conclusions; but it may be stated briefly that they are based on the fact that, if the powder be turned into gas before the projectile has moved from its position, the gas will expand a certain number of times before the shot leaves the muzzle—the number of volumes of expansion depending upon the proportion of space occupied by the powder-charge as compared with the total amount of space in the barrel. They have accordingly prepared a table which sets forth the number of foot-tons of work which each pound of powder is capable of producing according to the volumes of expansion that occur in the gun. Of course it is necessary to know the diameter and length of the bore, in order to ascertain the amount of space contained therein; and it is also necessary to know the amount of that space which is occupied by the powder.

Pounds of powder and foot-tons of energy are far too grand in scale to serve as units for purposes of calculation in what concerns sporting rifles. Accordingly, it has been found necessary to turn them into drams of powder and foot-pounds of energy. With this amount of alteration, the following short table will afford some notion of the longer table contained in the "Philosophical Transactions," except that it omits the fractional parts of volumes of expansion and the density of products of combustion.

Number of Volumes of Expansion.	Total work that one dram of gunpowder is capable of performing	Number of Volumes of Expansion	Total work that one dram of gunpowder is capable of performing
1	. . .	16	1174 foot-pounds.
2	492 foot-pounds	17	1192 ,,
3	607 ,,	18	1209 ,,
4	718 ,,	19	1225 ,,
5	800 ,,	20	1239 ,,
6	863 ,,	21	1253 ,,
7	915 ,,	22	1267 ,,
8	959 ,,	23	1280 ,,
9	997 ,,	24	1292 ,,
10	1030 ,,	25	1303 ,,
11	1060 ,,	26	1315 ,,
12	1087 ,,	27	1326 ,,
13	1112 ,,	28	1336 ,,
14	1134 ,,	29	1345 ,,
15	1155 ,,	30	1354 ,,

This table of the calculated maximum amount of work which gunpowder is capable of performing, is based on experimental results obtained during the investigations previously alluded to. The powder-pressure corresponding to a gravimetric density of unity is taken at 6554 atmospheres, equal to 43 tons per square inch, which is the corrected result for *perfectly dry* powder of Waltham Abbey manufacture, the explosive force thus being higher than when it contains moisture. This powder differs very little in composition from ordinary sporting (black) gunpowders; and the same table might be applied to mining or other powders, if taken in connection with a suitable "factor of effect" applicable to the special powder. If the powder is of less gravimetric density than unity—*i.e.*, if a measure of the powder weighs less than the same measure of water—strict accuracy would require an allowance to be made corresponding to the difference of density. Some sporting powders (especially when pressed down in a loaded cartridge) are of rather higher density than 1, but others are somewhat below; and it is scarcely necessary to complicate matters here by attempting to distinguish between them.

It will be observed, in the first line of the table, that no figures occur opposite to 1 volume of expansion; the reason being that nothing has been done. When the powder is shut up and fired, and the gas occupies only the same amount of space as the unfired powder, no work has been effected; when the force of the gas enlarges the space occupied, work has been done, but the amount would vary according to the resistance that has been overcome. The maximum amount of work which could be done by one dram of powder, in doubling the space occupied, would be 492 ft.-lb.; the maximum in three expansions would be 607 ft.-lb., and so on. Every additional expansion increases the amount of work done, but the rate of increase diminishes continuously, as the tension of the gas decreases. Thus, if one gunbarrel is of such a length that 3drs. of powder occupy $\frac{1}{10}$th of the bore, and another is of such length that 3drs. occupy only $\frac{1}{12}$th of the bore, the latter would have 12 expansions to 10 of the former. The total capacity for work in the one case would therefore be 3 (drs.) multiplied by 1030 ft.-lb., and in the other it would be 3 multiplied by 1087 ft.-lb.; consequently the same charge of powder would, in the one barrel, be able to do 151 ft.-lb. more work than it could do in the other.

Again, supposing that the barrel which allowed 12 volumes of expansion with 3drs. had its charge of powder increased to 4drs., there would be only room for 9 volumes of expansion; and its total capacity for work would be 4 times 997 ft.-lb. instead of 3 times 1087 ft.-lb. Thus, the powder-charge would be increased 33 per cent., while the maximum amount of work it could perform would be raised only 22 per cent. But the theoretical maximum never is attained, as will be shown farther on.

In order to work out any such estimations, it is necessary, of course, that the capacity of the barrel should be known, and likewise the space that the charge of powder would occupy therein. The areas of the principal Express and large-bore sporting rifles are as follows :

Express Rifles.		Large Bores.	
·400-bore	·126 sq. inch.	12-bore	·417 sq. inch.
·450 „	·159 „	10 „	·472 „
·500 „	·196 „	8 „	·548 „
·577 „	·261 „	4 „	·869 „

If, then, we have a gun of either of these bores, and a given number of inches in length, we find its cubic capacity by taking the fraction of a square inch which represents the area of the bore, and multiplying it by the number of inches in length of the barrel. To ascertain the number of volumes of expansion, we must know the amount of space occupied by the powder. A dram of powder of the gravimetric density of unity would occupy ·108 cubic inch of space; and if this be multiplied by the number of drams in the charge, and the product used as divisor of the cubic capacity of the barrel, the quotient will be the number of expansions in the barrel.

The following tables will show the result as applied to the rifles already alluded to ; the number of volumes of expansion of each rifle with the different charges being given, together with the calculated maximum energy or working-power. The energy is shown in two ways, viz., the amount per dram, and the total amount of the whole charge: the one will demonstrate the relative decrease of force per dram when increasing charges are fired from the same barrel, and the other will furnish means of comparison between the theoretical maximum calculated and the total effect obtained. The latter has already been given in the previous tables (pp. 101 and 104); but in order to afford a clearer perception of the difference of result, the percentage realised is stated in the last column of the present tables. As previously intimated, the theoretical maximum never is reached in practice, and the percentage that is obtained varies considerably, according to circumstances. In heavy ordnance, with very weighty projectiles, 90 per cent. or more may be realised ; but with small artillery the percentage drops to 50 per cent. or less. A somewhat similar result is found to occur with sporting rifles. The larger the bore the higher are the results usually obtained when the weight of powder and projectile increase proportionately with the bore ; and a larger percentage of the theoretical maximum from the same charge of powder results from an increased weight of bullet in the same barrel ; while the substitution of a spherical ball for an elongated bullet produces a considerable reduction per cent.

WORK DONE BY EXPRESS RIFLES

Rifle.	Barrel	Charge of Powder	Weight of Bullet	Volumes of Expansion of Gas	Energy of Powder burnt: Calculated Maximum: Whole Charge	Energy of Powder burnt: Calculated Maximum: Each Dram	Energy of Powder burnt: Percentage realised.
	·400 BORE.				Ft.-lb	Ft.-lb	
A	26in	3drs.	209grs.	10 06	3092	1031	52 6
	·450 BORE						
B	26in	5½drs	274grs	6 96	5008	911	48 5
C	28in.	4drs.	275grs	10 31	4159	1040	53 3
D A	26in	4¼drs	280grs.	9 01	4237	997	49 1
D B	same	same	365 ,,	same	same	same	55 2
E	26in	4drs	322grs	9 57	4061	1015	55 5
F	33 3/16in.	3⅛drs	480grs	15 71	3637	1170	50 6
	·500 BORE						
G A	26in	4drs	381½grs	11 82	4338	1085	54·5
G B	same	5 ,,	same	9 45	5063	1013	51·5
G C	same	4¼ ,,	*339grs	11 12	4521	1064	48·3
H	28in	5drs.	342grs	10 18	5328	1066	53 9
I	28in	5drs	444grs.	10 18	5328	1066	59 1
	·577 BORE.						
J A	26in.	5drs.	502grs.	12 59	5515	1103	53 1
J B	same	6 ,,	same	10 49	6270	1045	54 0
J C	same	same	*458½grs	same	same	same	48·4
J D	same	same	†287½ ,,	same	same	same	36 9
K	26in.	6drs.	591grs	10 49	6270	1045	58·2
L	28in	6drs.	648grs.	11 30	6409	1068	58·0
M	28in.	7drs	710grs.	9 68	7142	1020	66 4

* Hollow bullets. † Spherical.

WORK DONE BY LARGE-BORES.

Rifle	Barrel.	Charge of Powder.	Weight of Bullet.	Volumes of Expansion of Gas.	Energy of Powder burnt. Calculated Maximum. Whole Charge	Each Dram.	Percentage realised.
	12 BORE.				Ft.-lb.	Ft.-lb	
N A	26in.	4drs.	599¼grs.	25·12	5226	1307	38·7
N B	same	5 ,,	same	20 10	6204	1241	39·6
N C	same	6 ,,	same	16·75	7124	1187	41·8
N D	same	7 ,,	same	14·35	7889	1127	42·0
	10 BORE.						
O	26in.	8drs.	689¾grs.	14·20	9084	1136	40·73
P	‡28in.	same	same	15·29	9282	1160	40·70
Q	‡25¾in.	5drs.	698grs.	22·50	6112	1222	43·9
	8 BORE.						
R A	24in.	9drs.	875grs.	13·52	10,032	1115	42 6
R B	same	10 ,,	same	12·17	10,912	1091	42·5
R C	same	§10 ,,	same	same	same.	same	32·4
S A	26in.	10drs.	862grs.	13·18	11,157	1156	46·9
S B	same	same	‖1257 ,,	same	same	same	56·2
	4 BORES.						
T	24in.	14drs	1257½grs.	13·80	15,812	1128	44·4
U A	25⅝in.	¶12drs.	1250grs.	16·85	14,261	1118	41·5
U B	same	same	‖1882 ,,	same	same	same	51·8

‡ Smooth-bores. ‖ Conical bullets. ¶ No. 7 grain powder. § No. 8 grain.

We here find an indication of some probable causes of various results to which brief allusion has already been made in commenting on the previous tables. Where (as with J A and J B, N A, B, C, and D, R A, B, and C) the same rifle and bullet are used, with different charges of powder, the percentage of the theoretical maximum realised generally varies but little. The previous tables have shown that there is a falling off of effect as compared with the quantity of powder used; but the present figures show that the diminished result is a natural consequence of the altered condition of things, as the larger charge of powder has less opportunity of developing its energy. In the majority of cases, indeed, the larger charges of powder give a higher percentage than might be anticipated, except for the consideration that, with an increase of 20 per cent. of powder, there would not necessarily be a corresponding increase in frictional resistance to the bullet, or in absorption of heat by the barrel; and as a smaller proportion of the energy of the large charge would probably be lost in this way, the slight increase in percentage of effect may thus perhaps be accounted for. An exceptional result is found, however, with G A and G B, as here the smaller charge gives the higher percentage; but, although the same rifle was used, with bullets of equal weight, the velocities with the different charges of powder were not obtained on the same day; and there may have been such a change in the condition of the atmosphere as, if recorded, would account for the apparent irregularity of result. This seems to be the more likely, as other chronographic results taken on the second day also came out lower than had been anticipated.

Where (as with O and P) barrels of different length are used with similar charges, the percentages are generally about the same. In these cases O was a rifle and P a smooth-bore, fired with the same cartridges, and the smooth-bore gave a little higher velocity; but it had the longer barrel, and the percentage of the theoretical maximum, after allowing for the increased length, was almost exactly the same. In the case of the 4-bores, however, this does not hold good, for there the shorter barrel (T) gave a higher percentage than U A; but this result is doubtless due to the latter being used with powder of No. 7 grain. A still larger falling off is shown with R C, where No. 8 grain was used with the same barrel and ball as R B. Similar results have been found in the case of artillery: a higher percentage of effect is always given with the finer-grained powder, when used in the same gun and with the same projectile; but the disadvantage lies in the great additional strain on the gun that results from the more rapid explosion of the charge.

The means of comparison in the foregoing tables are not so numerous as could be wished, and the results, as here seen, are not always concordant; but, looking at the fact that the rifles were tried at different times, under atmospheric conditions which probably varied, but of which variations we have no record, and therefore cannot allow for, the results agree together quite as much as could be expected. We find, for example, that where the volumes of expansion run near together, the percentage realised follows pretty regularly the increased proportion of lead to powder. Here, for instance, are such of the Express rifles as afford means of comparison :

	Rifle.	Volumes of Expansion.	Proportion of Powder to Lead.	Percentage of Energy realised.
G_B	·500 bore	9·45	1 to 2·85	51·5
E	·450 „	9·57	1 to 2·93	55·5
M	·577 „	9·68	1 to 3·72	66·4
H	·500 „	10·18	1 to 2·40	53·9
I	·500 „	10·18	1 to 3·22	59·1
J_C	·577 „	10·49	1 to 2·80 (hollow)	48·4
J_B	same	same	1 to 3·06	54·0
K	·577 „	10·49	1 to 3·60	58·2
G_C	·500 „	11·12	1 to 2·92	48·3
G_A	same	11·82	1 to 3·49	54·5
L	·577 „	11·30	1 to 3·95	58·0

The large-bores, when used with spherical ball, always give lower percentages than the Express rifles, but when elongated projectiles are fired from the same rifles, with the same charge of powder, there is a great increase in the percentage, as will be seen with the conical bullets S_B and U_B in the following table :

	Rifle.	Volumes of Expansion.	Proportion of Powder to Lead.	Percentage of Energy realised.
R_A	8-bore	13·52	1 to 3·56	42·6
S_A	8-bore	13·18	1 to 3·15	46·9
S_B	same	same	1 to 4·59	56·2
T	4-bore	13·80	1 to 3·28	44·4
P	10-bore	15·29	1 to 3·15	40·7
N_C	12-bore	16·75	1 to 3·41	41·8
U_A	4-bore	16·85	1 to 3·81	41·5
U_B	same	same	1 to 5·73	51·8

It must be recollected, with respect to these percentages, that the theoretical maximum is based on the assumption that the powder is perfectly dry; and it is well known that the amount of moisture in the powder considerably affects its explosive force. Then there is loss of heat, by conduction of the metal in the barrel; and the smaller the bore the larger the proportion of heat lost, and consequently the smaller expansion of gas and least working power. Hence we see big guns and hundredweights of powder giving a much nearer approach to the theoretical maximum than small-bores and drams. But loss of heat alone is doubtless not responsible for the whole reduction in percentage; there is friction to be overcome, and the resistance of the air in the barrel. These would both operate in small bores to a greater degree than in large-bore guns.

Effect of Resistance on Velocity and Strain.

An endeavour has been made in previous pages to show that the energy of the powder increases with the amount of resistance offered by the bullet, and that by using heavier bullets with the same charge of powder a greater percentage of energy is realised, although there may be lower velocity with the heavier projectile.

Resistance of another character, such as arises from tightly turning over cartridge cases, and firmly fixing bullets in brass shells, is calculated to elicit a greater amount of force from the powder. So, too, the resistance resulting from the necessity of forcing the metal of the bullet into the grooves of the rifle, produces a further increase of force in the powder, as the initial movement of the projectile is retarded, and the powder has less space for the development of its gases; and the strain upon the breech, arising from this retardation, will depend upon the nature of the rifling, which is much deeper cut and sharper in twist in some than in others. What would be the relation between the extra force of propulsion developed in this way, and the effect of extra friction in lessening the velocity of the projectile, is difficult to say; but the main point in view here is to demonstrate that such development of force does arise from increased resistance; and two instances of burst guns that have come under my notice appear to be satisfactory illustrations of the fact.

One, a 12-bore, was loaded with a very small charge of Schultze (a fine-grained sample made before the company adopted its present mode of granulation); few wads were used, and the charge consequently did not nearly fill the paper case. The surplus paper was rolled up for nearly half an inch, being turned over and over by the machine till it formed a perfectly compact beading inside the mouth of the case; and yet the powder was in no way compressed, but, on the contrary, was rather loose within. A considerable amount of force would be requisite to drive the shot and wads through an obstruction such as here occurred; and, with a quick-burning powder like this, the whole would be consumed, and the gases in a high state of tension, in much less time than would be required to unroll the convolutions in the paper. Insufficient time being given for the shot to get into motion, it became a question of what was to give way first; and the question was answered by a piece of metal being driven out of the side of the barrel.

The other burst gun was a 16-bore, loaded with a larger charge of granulated Schultze powder, which, under ordinary circumstances, would scarcely be so rapid in combustion as the dust-like sample before mentioned. The charge was in a brass "Perfect" case, tightly crimped in; and the owner of the gun, after the accident, had an experiment made to ascertain the amount of force required to drive the shot and wads through the crimping. He had the base of the shell drilled out, the powder removed, and weights put on; and nearly a hundredweight had to be applied (109lb. if I remember rightly) before the charge of shot began to move. Here, then, the resistance would be about 1800 times as great as the mere weight of the shot, and (after what has been said at page 76 *et seq.*) it is not surprising that before time had elapsed to admit of motion in the shot, and thus permit of expansion in the powder-gases, the tension had become so high as to burst a not over-strong barrel.

As is usually the case, the results of experiments carried out with small arms are but confirmatory of what has been ascertained with respect to big guns; and the experiment just mentioned runs on very nearly the same lines as one alluded to by Professor Bashforth at page 16 of his "Treatise on the Motion of Projectiles." After stating that, "when quick-burning powder was used for large guns it was most important to consider the initial motion of the shot, so as to provide for an early increase of space for the gas to occupy," he comments on the law laid down by Professor Hélie as to the rifling of guns with an increasing twist, and then proceeds as follows (the *italics* being his own):

"It is undoubtedly right in principle to free the initial motion of the shot, as far as possible, from all needless obstructions. The increasing twist has, as we have seen, been tried in deference to this principle, only it is at present doubtful whether the advantages secured by its adoption counterbalance the practical disadvantages of its employment. But the Armstrong system of breechloading ignored all considerations of this kind, for a 'grip' in the bore was placed just in front of the seat of the shot, while the shot was covered with a thin coating of lead to take the rifling. An experiment was made at Woolwich in 1865 to determine the statical pressure required to force a 12lb. shot along the bore of an Armstrong breechloading gun. (Quarterly Proceedings of the Ordnance Select Committee, 1865, p. 23.) It was found that a pressure of from $16\frac{1}{4}$ to 20 tons was necessary to force a cold 12lb. shot through the 'grip' in front of the shot chamber, and a pressure of from 3 to $5\frac{1}{2}$ tons to force it along the bore. It is plain that the shot could not move forward before a tension of the exploding powder was sufficient to exert a pressure of 16 tons on the base of a 3-inch shot, and even after that the shot would move slowly. This would cause so *great a loss of time*, that probably the whole of the powder would be exploded before the shot had moved sensibly from its seat, and consequently the *gas would exert its greatest possible destructive force upon the gun.*"

Since 1865 considerable changes have been made both in the powder and the construction of big guns; but this principle applies to sporting rifles as well as artillery, and the increase of force with the latter is only on a larger scale than it is with small arms—the pressure being about 3000 times the weight of the projectile in the case mentioned in the above extract, and about 1800 times in that of the 16-bore which came under my notice.

Another artillery experiment shows that the retardation of initial movement in the projectile has the effect of increasing the velocity of the projectile as well as being likely to exercise a destructive force upon the gun; and in this respect it is confirmatory of the results shown by the experiments with Express rifles, viz., that the greater resistance of the heavier bullet induces greater energy in the powder; and it also proves that increased resistance, where the projectile is not heavier, likewise induces greater energy, which, under these circumstances, takes the form of enhanced velocity. In Messrs. Noble and Abel's second paper in the "Philosophical Transactions" (1880, pp. 242-3), it is stated that it had been found that with certain breech-loading guns a superior effect was attained by substituting copper rings for lead coating on the iron shot, and it had been assumed that the cause of this superiority was due to the less friction of the copper rings in the passage of the shot up the bore. Experiments were carried out to ascertain the facts; shots were fired coated with the ordinary service quantity of lead, and the results compared with those of others on which the lead had been considerably reduced, so as to diminish friction. The reduction of friction did not increase the realised amount of energy in the powder, but, on the contrary, it was slightly reduced. Rounds were then fired with shell fitted with copper rings, and there was a gain in velocity, but the pressure in the chamber of the gun was found to be raised from 16·8 tons to 18·6 tons per square inch, showing that the increased effect had not been caused by a reduction of friction, but was owing to the increased difficulty of forcing the copper bands into the grooves, and to the powder being consequently burnt earlier in the bore. The paper then proceeds as follows :

"To show the effect of a greater or less degree of retention of the shot in its chamber in as clear a light as possible, the following experiments were made. Four projectiles for a 12-centimetre B.L. gun were manufactured of precisely the same weight, and which differed from one another in the following respect only : that two of these were fitted with a rotating gas-check of such a form that a high pressure would be necessary to force the projectile into the bore ; the two others being fitted with gas-checks of a form such that a comparatively feeble pressure only would be requisite. The copper surfaces in contact with the bore were the same in each case.

Two rounds, one with each form of gas-check, were then fired with a charge of 7lb. of R.L.G. powder, every condition, except as noted, being precisely the same. The velocities with the two forms were respectively 1609 feet per second and 1512 feet per second, giving rise to 82·04 and 72·44 foot-tons per lb. of powder. The chamber pressures were respectively 15·2 and 12·0 tons per square inch.

Two further rounds were then fired with 7½lb. R.L.G., when velocities of 1644 and 1544 feet per second, or energies per lb. of 79·94 and 70·51 foot-tons were respectively obtained, the chamber pressures in this case being 16·4 and 14·1 tons per square inch.

These experiments prove in a most complete manner that, although there may be, and doubtless is, some difference in the amount of friction due to the employment of lead or copper as the driving or rotating material, that difference is perfectly insignificant when compared with the alteration in energy due to the projectile being more or less retained in its initial position, and thus permitting the powder to be consumed earlier and in a more complete manner."

The "foot-tons of energy per lb. of powder" in the above quotation are obtained from the number of expansions in the bore, and correspond with our "foot-pounds of energy per dram" in the table about Express rifles on page 110. The results shown in the quotation will become more clear if tabulated. In the first place, the connection between the chamber pressure and the muzzle velocity, with merely an increase of powder, may be shown thus:

	Charge of Powder	Velocity	Chamber Pressure
	7lb.	1512 ft.-sec.	12 0 tons.
	7½lb	1544 „	14 1 „
Increase	7 per cent.	2·1 per cent.	17 5 per cent.

The next will show the difference of effect with both charges when the resistance was increased:

Resistance	Muzzle Velocity from		Chamber Pressure from	
	7lb powder	7½lb powder	7lb powder	7½lb powder
Small	1512 ft.-sec.	1544 ft.-sec.	12 0 tons	14 1 tons.
Great	1609 „	1644 „	15 2 „	16 4 „
Increase	6 4 per cent.	7·1 per cent.	26 7 p. cent	11 6 p cen

It will be observed that the increase of velocity from the greater resistance is about three times as much as that arising from the increase of powder. Also, that the lesser charge of powder with great resistance gives higher strain on the breech than the larger charge with small resistance. And, further, that although the large charge more than keeps up the percentage of increased velocity arising from greater resistance, yet the *relative* increase in chamber-pressure is much smaller than before.

Taking, too, the total amount of work done, both by increase of powder and increase of resistance, we find the percentage from the latter was again much higher than from the former.

In the next short table, the increase from the extra powder is given at the end of the line, while that due to extra resistance is given beneath.

Resistance.	Total work done by 7lb powder.		Total work done by 7½lb powder		Increase.
Small	507 foot-tons	...	529 foot-tons	...	4·3 per cent.
Great	574 ,,	...	599 ,,	...	4·4 ,,
Increase...	13·2 per cent.		13·4 per cent.		

Returning again to small arms, we have another mode of showing the different degrees of force in different rifles. The four accompanying woodcuts represent four crusher-gauges made of lead, which were kindly furnished by Major McClintock, R.A., who had carried out experiments with them. Fig. 11 is the full-size representation of one that has not been used. Fig. 12 represents one that has been submitted to the pressure arising from the Snider-Enfield charge of 70grs. of powder

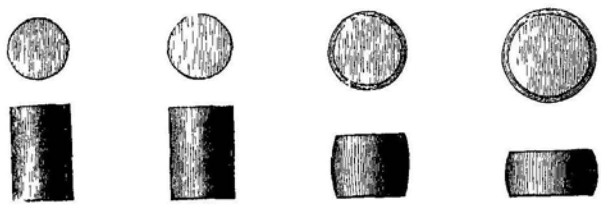

FIG. 11. FIG. 12 FIG. 13. FIG. 14.

with 480gr. bullet of ·577 bore; it has been shortened a trifle by the explosion, but otherwise is little altered in shape. Fig. 13 shows the greater effect produced by the Martini-Henry charge of 85grs. with a 480gr. bullet of ·450 bore, by which it has been shortened and made more rotund; and Fig. 14, which is very cheese-like in shape, represents the still greater amount of "crush" effected by a Gatling cartridge. The latter has the same powder and bullet as the Martini, but is inclosed in a stout brass case, very tightly clasping the projectile, which thus gives much more resistance to the expansion of the gases. The relative pressures on these bullets were estimated to be—Snider, from 2 to $2\frac{1}{2}$ tons; Martini, $4\frac{1}{2}$ to 5 tons; and Gatling, about 7 tons per square inch. The area of the ·577 being about $1\frac{2}{3}$ that of the ·450 bore, the whole pressure given to the Snider bullet would be approaching that of the Martini, and, the bullets being equal in weight, their muzzle velocities would be not very far apart; but the "pressure per square inch" on the circumference of the bore would, in the Martini, be very much greater than in the Snider, and greater strength of barrel would be required to withstand the strain. It is not uncommon for small barrels to be made thinner than large-bores because the charge of powder is less; but, as previously pointed out, the strain does not depend alone upon the quantity of powder; and in small-bores the resistance from turning-over, &c., is sometimes even greater than with large-bores. Possibly this may explain the number of accidents that have occurred of late with 16 and 20-bore guns, the percentage of those that have been burst by E.C. and Schultze powder being apparently much larger than in the case of 12-bores.

But, returning to the crusher-gauge experiments, the most remarkable feature is the enhancement of force by the increased resistance of the Gatling cartridge-case, the bullet and powder being just the same as those of the Martini. I may add that Major McClintock considers these estimates as but approximately correct, the pressures of only a few rounds of each having been taken. These pressures, moreover, were not taken in the chamber itself, but just in front of the chamber; consequently the gas would not operate on the crusher-gauge until after the bullet had been moved, and when the pressure had possibly somewhat diminished.

It is a well-known fact that many of the most skilful rifle-shots prefer to load their own cartridges, as they thereby can insure an equality of manipulation that is not to be expected from those that are commercially loaded; and the regularity of shooting well repays them for their pains. I am convinced, from a careful inspection of the targets at the *Field* Rifle Trial at Putney, in October, 1883, that difference of care in the loading of the cartridges had a good deal to do with some of the weapons not giving better results as compared with others. On looking at chronograph records, too, it is not an uncommon thing to find successive shots in the same series vary 50 feet or more in their muzzle velocity, while in other batches a remarkable degree of uniformity is shown; and it seems by no means improbable that an important factor in such variations may be the different amount of resistance arising from the varying degrees of firmness with which the bullets are fixed into the brass shells. Some carefully carried out experiments to ascertain the facts might be advantageous in various ways, and, amongst others, in connection with the subject-matter of the ensuing section.

Effect of Atmospheric Pressure on the Development of Force in Powder.

In a previous chapter (p. 65 *et seq.*) allusion has been made to the differences in amount of bullet-drop that may arise under reduced barometrical pressures with a given muzzle velocity; and it is intimated that the effect of change of temperature, &c., would be touched on in the chapter treating on the calculation of the trajectory. There is, however, another point which deserves consideration, in connection with the subject now under discussion, viz., the effect which may be produced on the velocity of the bullet at the muzzle by the difference of resistance to its initial motion at the breech of the gun, and that is, the effect of atmospheric pressure in varying this resistance. Additional point has been given to this matter by the following letter recently addressed to Mr. Walsh:

98, New Bond-street, London, W., Feb. 6, 1884.

MY DEAR SIR,—Frequently I have had complaints from correspondents who have been shooting with Expresses in the Himalayas in India, and the Rocky Mountains in America, that their rifles shoot low. I could not understand it, knowing that the rifles were correctly sighted, and in most cases pretty sure that the ammunition was right. One of these correspondents came over on sick leave, and went to our ground, and, to his surprise, instead of the rifle shooting some 12 or 14 inches low, as he said it did, it appeared to be about right. Again, Major C. called to-day and told me much the same thing. Well, this *morning* I received an order for an Express from America. The writer of this order particularly mentions that the barrels must be extra long, and sighted rather high, as he is shooting some 9000 feet or more above sea-level; and he says that, at these high altitudes, elevations are very different, and he believes the powder does not all burn. Will you ask your scientific friends if there is anything in it? If there is, it may be worth mentioning in your book.

Yours faithfully,

HENRY HOLLAND.

J. H. Walsh, Esq.

Nothing is here said as to temperatures, or to length of range; and, as remarked in the previous chapter, the lowness of temperature at high altitudes tends to counteract the effect produced by the height above sea-level, while the variation in drop would greatly depend on length of range.

The observations made in a previous chapter had reference to the effect which would be produced on certain bullets supposing that they had the muzzle velocities there stated, and that the temperature was about the normal standard. The effect of reduced temperatures will come on for future consideration; and it will suffice here to say that a reduction of about 15° in temperature would compensate for a fall of an inch in the barometer. It is obvious, therefore, that the temperature would not be so low as alone to counteract the effect of the barometrical pressure being reduced by 10 inches, as in the 11,000 feet elevation assumed for the calculations previously given. The drop in the bullet alluded to in Mr. Holland's letter must therefore be due, in great measure, to some other cause, and that cause most probably is the amount of atmospheric pressure in the bore of the gun.

In an article of mine, inserted in the first volume of this work, some remarks were made (pp. 305-6) with respect to the different amounts of force given forth by gunpowder under different degrees of restraint. After stating that the force of the explosion increases with the strength of the envelope in which the powder is confined, and that the ignition of unconfined powder in the open air (under ordinary conditions of atmospheric pressure) does not show the lowest development of force, the article proceeds as follows:

"If the explosive be fired in a rarefied atmosphere, as on a high mountain or under the exhausted receiver of an air pump, its violence decreases according as the pressure is reduced below the ordinary pressure of the atmosphere. This difference of resistance has an important influence on time-fuses; for Quartermaster Mitchell found, by some experiments carried out in India, that fuses which burnt out in 14 seconds at the sea-level, required no less than 18 seconds in the hills, at an elevation of 7300 feet; and Dr. Frankland, by means of experiments in artificially rarefied atmospheres, discovered the law of this variation, which he explained in a paper read before the Royal United Service Institution. He showed that the mere change in our daily atmospheric pressures caused an appreciable difference in result, as a fall of one inch from the ordinary barometrical standard of 30 inches would decrease the time of combustion by $\frac{1}{30}$th; so that a half-minute fuse would require about 31 seconds to burn out at 29 inch pressure, and rather more than 32 seconds at 28 inches. At 7300 feet the barometrical standard is rather under 23 inches, and the time occupied in the combustion of the fuse was increased nearly one-fourth."

This appears to bear on the effects alluded to by Mr. Holland's correspondents. We have already seen, from the experimental results with sporting rifles and big guns lately commented on, that when the resistance to the initial motion of the shot is increased, the powder exhibits greater energy; or, to put it the other way, whenever the amount of resistance is lessened, the powder, having less work to do, does not put forth so much energy. The projectile begins to move under a lower pressure, and the powder gases never acquire so high a tension.

Let us apply this to the state of affairs depicted in Mr. Holland's letter. When the rifle is fired, motion on the part of the bullet is resisted (1) by the weight of the bullet itself, which we will assume to be one of ·450 bore, weighing 350grs.; (2) it is further resisted by crimping or swedging, which fixes the bullet in the case, as well as by the rifling, into which the metal of the projectile has to be forced—giving a combined amount of resistance which it is not easy to estimate, but which must be vastly beyond the mere weight of the bullet; and (3) the bullet has bearing on it an atmospheric pressure of about 15lb. to the square inch. The rifle being of ·450 calibre, this pressure would amount to nearly $2\frac{1}{2}$lb., or about 50 times the weight of the 350gr. bullet—that is, supposing the gun were fired near the sea-level. But if it be fired at an elevation of, say, 11,000 feet, where the barometer would stand at about 20″, the atmospheric resistance would only be about 10lb. to the square inch, and thus be only about 34 times the weight of the bullet. The conditions No. 1 and No. 2 would remain as before, but No. 3 would only operate to two-thirds of its previous extent; a less amount of resistance would be offered to the expansion of the gases, and they would therefore develope less energy; with less energetic propulsion, the bullet would have a lower muzzle velocity, and the bullet would drop more in a given distance owing to its slowness of flight.

Such is a theoretical explanation of the effect described; but no practical means, as far as I am aware, have ever been adopted to test it. And it seems scarcely possible to prove it satisfactorily without careful experiments by means of scientific instruments, such as the chronograph, taken to high altitudes, so as to ascertain the muzzle velocity of rifles with ammunition which has been proved to give certain velocities near the sea-level. An approximate estimate of the muzzle velocity might perhaps be formed by methods of calculation hereafter to be described; but they would only be approximations, and open to the charge of being erroneous. If, however, anyone would carry out a scientific inquiry into the matter, facts of considerable interest would doubtless be obtained; but, until such is done, one cannot do more than speculate as to what the results would be. Projectiles of light weight would be most affected; but otherwise the results would be likely to vary with nearly every rifle and bullet, according to the proportion which atmospheric resistance bears to other forms of resistance in the barrel.

Supposing, however, it to be proved that diminished atmospheric pressure has the effect of reducing the muzzle velocity of the bullet, there is an opening for further experiment to ascertain whether the loss of resistance might not be remedied by the sportsman at high altitudes carrying a light swedging apparatus to crimp the brass shell more firmly into the bullet.

Effect of Moisture on Gunpowder.

The quantity of moisture in gunpowder considerably affects its rapidity of explosion and the amount of energy it imparts to the projectile. Whatever the proportion of water in the powder, it has to be turned into steam by the combustion of the other ingredients; consequently inflammation is retarded, and the heat, which would have increased the explosive force, is considerably lessened. The difference in the amount of work done by powders containing different proportions of moisture, but otherwise exactly alike, was tested by Messrs. Noble and Abel They experimented with a series of samples of pebble powder, carefully prepared with proportions of moisture varying from 0 70 to 1·55 per cent., and the muzzle velocities of the shot, and maximum pressures in the cannon from which they were fired, were found to be as follows:

Percentage of Moisture	Muzzle Velocity	Maximum Pressures	Percentage of Moisture	Muzzle Velocity	Maximum Pressure
	Ft per sec	Tons per sq in		Ft per sec	Tons per sq in.
0 70	1545	22 02	1 15	1514 5	19 37
0 75	1541	21 70	1 20	1512	19 12
0 80	1537	21 38	1 25	1509 5	18 87
0 85	1533 5	21 07	1 30	1507	18 63
0 90	1530	20 77	1 35	1504 5	18 40
0 95	1526 5	20 47	1 40	1502	18 18
1 00	1523 5	20 18	1 45	1499 5	17 97
1 05	1520 5	19 90	1 50	1497 5	17 76
1 10	1517 5	19 63	1 55	1495 5	17 55

The authors of the paper add: "From this table it will be seen that by the addition of considerably less than 1 per cent. of moisture, the muzzle velocity is reduced by about 60 feet, and the maximum pressure by about 20 per cent., pointing obviously to a much more rapid combustion in the case of the drier powder."

Some examples of results obtained in experiments carried out by Capt. J E. Greer, of the United States Ordnance Department, are also interesting.

Two kegs of fine-grain powder were taken into a room kept heated by a stove night and day. One keg was opened, and a sample therefrom was exposed in an open vessel in the room for three days, at the end of which time it was made up into cartridges. The other keg was then opened, and cartridges made up from the unexposed powder. Both samples of cartridges were tested. Those loaded with the powder which had undergone three days' drying gave an initial velocity of 1391 feet per second; those loaded with the undried powder gave only 1340 feet per second.

Some of the dried powder from keg No. 1 was then placed under a covered porch in the open air, and left exposed for three days, during part of which time it rained almost incessantly. Cartridges were made up from this powder; and the initial velocity, which had been 1391 ft.-sec. when the powder was dry, now fell to 1347 ft.-sec.

More samples of the same powder were exposed to the air of a heated room, for periods of three, six, and nine days respectively, after which they were made up into cartridges, and kept for four months. At the end of that time they were tested, and it was found that the powder dried for three days gave 1390 ft.-sec. velocity; that dried for six days gave 1395 ft.-sec.; and that dried for nine days gave 1407 ft.-sec. Evidently the cartridges must have been kept in a very dry place in the interim, as the powder that had undergone three day's drying gave at the end of four months virtually the same velocity as had been given when it was first dried.

A curious instance of the difference in the effect produced by the damping and re-drying of powder occurred in the course of some experiments carried out on behalf of the United States Government by Major Mordecai. One sample of powder, by reason of its high density and slow rate of combustion, gave a lower velocity than some other powders with which it was tested. The different powders were exposed to a very damp atmosphere for a long time, and subsequently re-dried. Most of them had deteriorated more or less; but this very dense sample gave better results than it had given originally. The moisture had caused the grains to swell, and when re-dried they retained their enlarged size; consequently they were more pervious, and, from their more rapid combustion, imparted higher velocity to the shot.

does it necessarily strike him, without explanation, that if he fires at an object at 100 yards, with a rifle sighted for double that distance, the bullet will hit considerably above the line of aim. That such must be the case will, however, be seen by the illustration given opposite (Fig. 15), which is drawn, however, on an exaggerated scale of elevation, as compared with length of range, in order to adapt it to the dimensions of the page. The line *a b*—a continuation of the long axis of the barrel—shows the *line of fire*, or *projection*, or *elevation*; and, were it not that the bullet is attracted to the earth by the force of gravity, the line of its flight throughout would be coincident with the line of fire, and it would strike any object placed at *b*. The line *d e*, which is the *line of aim* or *sight* or *vision*, is carried direct from the back to the front sight, and onwards to the object aimed at. But neither the line of aim nor the line of projection indicates the line of flight of the bullet, which takes a curved course between these two straight lines—apparently ascending for abc half of the range and descending for the rest of the though really dropping from the line of projectior very first.

It will be observed that the curve keeps pre line of fire in the early portion of the range, way between the two lines at the half dista falls off much more rapidly from the line previously remarked, the effect produ muzzle of the rifle, to counteract the fall uniform throughout the bullet's flight which the bullet is fired rises in hei the increase of distance, whereas in proportion to the "square" of the compensatory elevation must the beginning of the range, and the bullet will first rise and then

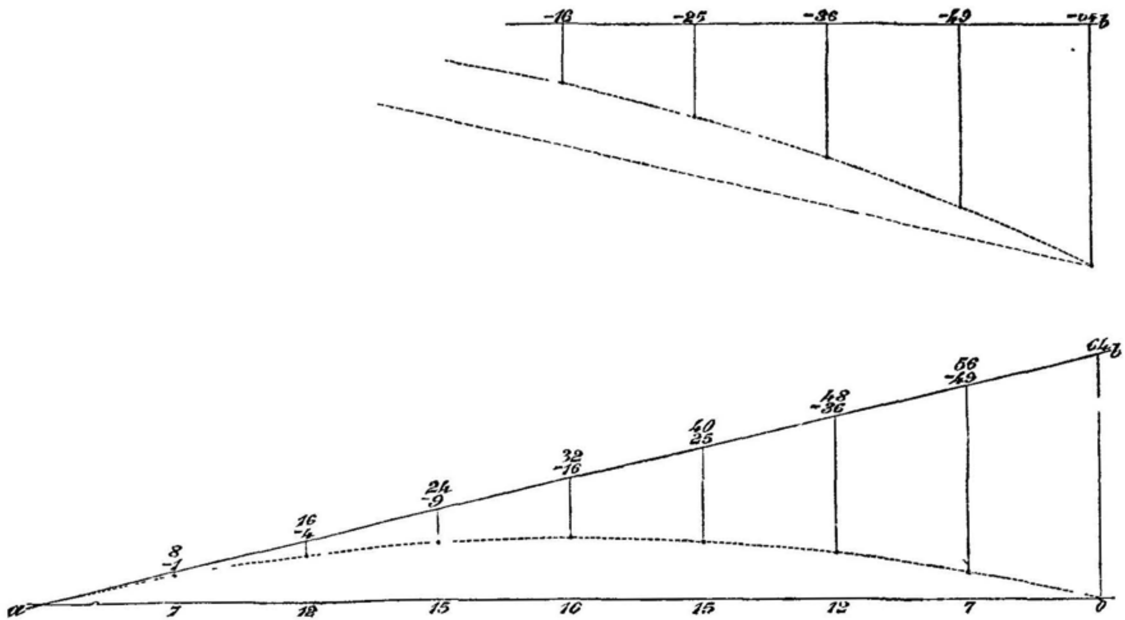

FIG. 18.

distance for which the rifle has been sighted, the projectile will have come down again to a level with the line of aim.

A tolerably good representation of the effect of these counter-influences may be obtained by means of a rod from which beads are suspended by threads varying in length, as shown in the accompanying diagram (Fig. 17).

Here the rod *a b* (which is supposed to represent the line of fire or projection) is horizontal, to illustrate the case of a gun in which there is no elevation whatever to counteract the fall of the projectile; consequently, in such case the line of fire and the line of aim would be parallel, supposing the barrel to have no increase of thickness at the breech. The suspended beads mark the course of the bullet, and the length of each thread shows the amount of fall from the line of projection at that point. The rod may be taken to represent a range of any given length, and the figure 1 over the first thread may represent full inches or fractional numbers as desired; but here it will be easier to consider the first thread as one inch long, the whole range as 200 yards, and the divisions as 25 yard

For the sake of simplicity, and to avoid the use of numbers, it will be assumed that the velocity throughout, and consequently that the e represent equal times. This, of course, is not for, if equal times were accurately represer between the threads would gradually dir other hand, if the distances be taken as of the early threads would require to and the others somewhat longer.

Supposing, then, that in the tim 25 yards of the range a bullet is the straight line, it will, in the n length, descend in accordance w the threads in the diagram; *i.e.* being 1in., it would be 4in.

increasing in the third to 9in., and s^ on, in accordance with the square of the number of periods, as already set forth at page 52, in the chapter on the drop of the bullet.

But, although we have seen how the bullet will fall if we hold the rifle in a perfectly horizontal position, we seldom want to use one in that way, and accordingly we lift the muzzle till the bullet starts at a greater or less angle with the horizon. Let us say that the muzzle is raised to such a point that the bullet will strike on the line of sight after traversing 200 yards. The raising of the muzzle makes no difference in the velocity of the projectile (except, as in the case of artillery, the shot ascends to very great heights, where density of the air is diminished); nor will it interfere with the action of the force of gravity; and, as the time would thus remain the same for the same distance, the amount of drop would also be unaltered. Accordingly, let us lift the rod which represents the line of projection (*a b*) until the last bead touches the line of sight (*a c*), when every intervening
raised above the line of sight, as shown in the other
Fig. 18).

'o compensate for the fall of 64 inches in 200 yards,
ɔ be such that the line of projection will, at the
ıge, be taken up to the point *b*, 64 inches
ıf sight. The bullet, however, rises but a
at height, as the operation of the force of
vn by its obstructing the ascent of the
of the range, and pulling the projectile
the middle point. At the beginning,
dotted curve in the diagram, the
the line of projection is trifling;
than a thousandth part of an
me to accumulate, and the space
ime the fall amounts to an inch;
tion has ascended 8in. above the

line of sight, as is indicated by the figures on the diagram, where the topmost numbers denote the rise of the angle, the negative numbers immediately underneath indicate the fall of the bullet, and the numbers below the line of sight give the difference between the two, or, in other words, the height of the trajectory at each point. So the counter-influences proceed, till the rapid ratio of descent by force of gravity overmasters the slower ratio of rise by the angle of elevation, and then down comes the bullet towards the level of the line of sight.

So high a trajectory as here given does not, we will suppose, meet our requirements. Let us see what will be the result of shortening the range to 150 yards. We therefore reduce the angle of elevation, and lower the rod accordingly till the sixth bead touches the line of sight. Then we find the height of the trajectory reduced to about one half of what it was before, so great has been the effect of the drop of the bullet in the latter portion of the range, where two beads will now hang under the line of sight. If we lower the rod there will be a further reduction in the height of the trajectory; and when the 100 yards bead touches the line find the trajectory only one-fourth as high as 200 yards.

This, however, as before stated, is on the the bullet retains the same velocity; but cannot have a bullet that loses no spee a trajectory so flat as here alluded to. T is not meant to refer to the curve as diagram; for in order to represent a space of a few inches, the vertic a larger scale, or they would be in meant that, in a range of 200 y necessarily be the number of inches the diagram; for the height wou the speed of the bullet, and the consequent time during which the force of gravity would be in action to pull it down towards the earth. But, supposing the time of flight were such that the bullet drops 64 inches in 200 yards, the height of the trajectory must exceed 16 inches; and the extent of the excess would depend upon the form and weight of the projectile.

In Fig. 18, with an assumed equality of speed, it will be seen that the height of the imaginary trajectory at the middle point is exactly midway between the line of sight and the line of projection, and consequently that it is one-fourth the height of the total fall in the whole range; at 50 yards and 150 yards, too, the beads are equal in height. But actual trajectories never have this equality, because the first part of the distance is travelled at greater speed than the last; accordingly the bullet continues to rise somewhat beyond the middle point of the range, and the highest point of the trajectory is always more than *one-fourth* of the entire fall.
ght varies at different points with different rifles and
nd it will be higher with a spherical ball than with
bullet that traverses the same distance in the
time; for the longer and heavier the bullet
its diameter, the less will it vary in speed,
ll it approach in regularity to the imaginary
as been given. On the other hand, the
ler to accomplish the same distance in the
rt with greater velocity, and it would
higher than the elongated bullet until
nalised. By reason of its greater
y drop less in the first part of
after passing the turning-point, it
y than the long bullet, owing to a
would not be until this loss had
gain that the two bullets would