MODERN GUNS

AND

SMOKELESS POWDER....

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PART I.

INTRODUCTION.

GUNPOWDER, the oldest of all explosives, has been the subject of many scientific investigations, supported by innumerable experiments; but Nature guards her secrets well; and to this day it cannot be said that the cycle of chemical changes brought about by the combustion of gunpowder is thoroughly understood.

Its original components vary, but are generally about 75 parts potassium nitrate, 15 parts carbon, and 10 parts sulphur, with other ingredients sometimes added. These materials, when simply mixed together, burn with considerable vigour, but cannot rank as an explosive until they have been thoroughly incorporated, so that the different molecules are brought into such close proximity that each finds a neighbour ready and willing to combine on the smallest encouragement.

Heat furnishes the necessary stimulus, by promoting chemical activity; and, when combined with concussion, the molecules are driven closer together, and this intimate association accelerates their combination.

The effect of mere concussion is shown to greater advantage when any of the more dangerous explosives, such as iodide of nitrogen, are subjected to experiment. This substance is very easily prepared, and when dry detonates violently if touched, or even when dropped on water. It is altogether so unstable as to be unfit for any military purposes. Gunpowder, however, is not a chemical compound; it is only a mixture of materials, the molecules of which are set by art in such positions as do not tend to exercise their natural affinities without external aid. Gunpowder, therefore, is eminently stable. But it is a somewhat intractable explosive, being violent and uncertain in its action, and the rate of its explosion cannot be held under sufficient control.

However the composition, density, or size of grain be altered, gunpowder does not give the same moderate pressures that can be secured from smokeless powders, although these are essentially unstable chemical compounds, which undergo rapid decomposition, and produce only permanent gases. They have been known for a long time past, but only within the last few years have they received marked attention by every military nation, under the name of "smokeless powders." These are simply violent explosives toned down to such a slow rate of decomposition as to be within the endurance limits of the strongest metal, steel, now universally employed in the construction of heavy artillery. This process of toning down the rate of combustion can be carried to any reasonable extent; and now for the first time in history that branch of military engineering which includes the designing and construction of heavy guns, has been able to reckon upon the most suitable pressures for propelling a projectile with any desired velocity, instead of being obliged to accept the pressures given by the explosion of gunpowder.

Modern explosives, then, including all smokeless powders, have their molecules in far more intimate propinquity than gunpowder, for they are true chemical compounds, held together by attractions so feeble that they possess an inherent tendency to re-arrange themselves in new gaseous forms, thus eliminating large quantities of nitrogen gas, which is the intruding unstable element in most, if not all, explosives. Any reliable explosive for military or engineering purposes should comport itself to the following conditions :—

(1.) That it shall not be too unstable, but be safe to manufacture and handle;

(2.) That its combustion shall be complete, producing little or no smoke, no noxious or irrespirable gases, and no residuum;

(3.) That it shall not suffer deterioration by time or exposure to ordinary climatic influence;

(4.) That it shall not foul the barrel or tube or damage it by excessive heat or pressure;

(5.) That it shall have high power with a low specific gravity, so as to give a light cartridge;

(6.) That it shall be uniform in composition and ballistic properties, giving high and regular velocities with moderate and regular pressures, and a flat trajectory;

(7.) That its curve of pressures shall approximately follow the requirements for propelling a shot.

It is the judicious blend of these several qualities that constitutes a good explosive; and whether the molecules are mechanically mixed, as gunpowder, or held together by chemical affinity like guncotton, their action is subject to two sets of laws: one relating to their chemical composition, and the other to their mechanical condition. The new explosives differ from gunpowder only in respect of chemical composition, but they have certain mechanical properties, and these can be regulated by similar rules to those which have been so far successful in adapting modern gunpowder to modern artillery.

The forces required for propelling a shot, and the principal explosives, will be dealt with in this memorandum from a practical point of view, and an endeavour will be made to place the whole subject clearly before the reader, without encumbering it with mathematical formulæ, which too often pass as explanations of things that nobody understands.

Influence of Modern Explosives upon Modern Guns.

As the explosive can now be considered in relationship to the gun, rather than as heretofore adapting the gun to the explosive, it follows that the first place can be given to the necessities of mechanical construction ; and guns need no longer be designed strong enough to resist so violent an explosive as gunpowder.

Having regard to this freedom, it is intended in the present memorandum to consider the impelling forces upon a shot from a somewhat new point of view, which, although familiar in some degree to engineers, in other applications has not, so far as the authors are aware, been applied to ballistic questions, nor heard of in this country, nor published abroad.

At present no acknowledged or established system exists, by which any series of guns can be designed ; all is haphazard and confusion, every nation having its own views, and holding them pertinaciously with much needless mystery.

An attempt will now be made to place the construction of guns upon a systematic basis ; then after having put forward a simple theoretical investigation based upon well-known dynamic laws, other chapters will follow describing modern explosives and machinery required for their manufacture. Gunpowder is by no means so far relegated to the limbo of forgotten things that a short dissertation upon its qualities, properties, and general behaviour, can be considered out of place; and as these particulars form a measure or standard for comparison with other explosives, a full consideration of them cannot fail to prove eminently useful.

In making this examination, it must be noted that guns and powder are designed and made to suit each other, so it will be desirable in the first instance to ascertain the nature and incidence of those forces, which suffice, and no more than suffice, for producing a given muzzle velocity—that is, the rate in feet per second at which a shot leaves a gun.

Forces required to Propel a Shot.

The uniform attractive force of gravity acting upon a falling body, adds equal increments of velocity in equal periods of time, giving a velocity at the end of one second equal to 32·2 feet; but a sudden evolution of gases in the chamber of a gun produces a high initial pressure, which gradually diminishes as the gases expand, lowering their temperature and accelerating the shot, until its full muzzle velocity has been acquired; all this is done within a fractional part of a second of time.

The explosion of gunpowder thus differing altogether from the action of gravity, a shot does not receive equal increments of acceleration in equal times, as it would do if under the influence of a constant pressure like gravity, but it occupies a position analogous to that of a steam-engine piston, accelerated during the first half of its stroke by the expansion of high-pressure steam, or like the piston of a gas-engine, accelerated in like manner by an explosion of mixed gases.

Before a manufacturer can be expected to provide a suitable explosive for any given rifle or gun, it is obviously desirable that he should understand something as to the actual conditions under which a shot should be impelled.

The present memorandum has been written, not as a complete essay on the manufacture of rifled ordnance, but only treating the subject so far as may be necessary for guidance in the production of suitable explosives for rifles, machine guns, or heavy ordnance. Knowing the muzzle velocity sometimes erroneously called "initial velocity," and the distance a shot travels in the gun before being discharged—knowing also its weight and diameter, the average pressure required to impart this velocity can be ascertained from the ordinary laws of dynamics. Again, knowing the final pitch of rifling and rotations of the shot per second, the pressure necessary to produce this rotation can also be easily calculated. Expelling such air as is found in the bore and overcoming friction are items which some writers take notice of, but which are so utterly insignificant in comparison with the heavy pressures required for impelling the shot, that no practical objection exists to omitting them altogether. Even the pressure required to give rotation to a shot amounts to no more than a small fraction of a ton per square inch. Formerly the action of studs upon the rifling absorbed considerable power before the gas check was invented, yet this was not a legitimate frictional resistance, but was due to inadequate surfaces exposed to pressure.

The object all gun constructors have in view is to give the highest possible muzzle velocity to a shot with a minimum strain upon the gun, and this must be accomplished with due regard to an economical expenditure of powder.

A high initial pressure developed in the space formerly occupied by a solid explosive is succeeded by expansion driving the shot before it by forces which decrease with great rapidity, and the gun is like a steam-engine working with a very high rate of expansion in a single cylinder, without the chance of any gain by compounding; and the usual pressure curve of fired gunpowder is far from representing a sequence of pressures conducive to longevity in a gun.

Indeed, their destructive effects become powerfully conspicuous in the larger class of heavy guns, where the metal is often subjected to strains beyond its elastic limits, and dangerously near to its point of final rupture.

The numerous attempts to remedy this state of things attest the extent of the evil. Selecting a slow-burning powder, enlarging the size of the grains, and increasing their density, are legitimate remedies; but when it comes to allowing an air space for unapplied expansion, the remedy becomes a manifest waste of energy that ought to be reserved for impelling the shot.

It is so much more satisfactory to follow any line of argument by observing its practical application, than by using letters, symbols, or mathematical formulæ, that this system will be adopted in the present memorandum, and it is intended to take advantage of an old, some may say "out of date," but singularly instructive experiment—an experiment conducted with the greatest care and accuracy, and well known to all artillerists. This will be used to exemplify a theory newly applied to gunnery and the practical results arising therefrom. In this experiment a 38-ton Armstrong gun 12·5 inches calibre was provided with numerous Crusher gauges for ascertaining the pressure at every part of the travel of the shot, and electrical appliances were also used, whereby its velocity could be tabulated, and one set of data thus served as a check upon the other.

EXPERIMENTS ON 38-TON GUN.

The following data are given in relation to experiments on this gun. The letters preceding are the same as are recommended for symbols in the 'Text Book of Gunnery.'

Diameter of calibre . . = 12·5 inches.
Charge of $1\frac{1}{2}''$ cubical powder = 130 lbs.
Area of base of shot . . = 122·7 square inches.

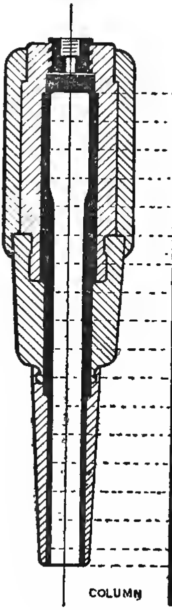
Length of cartridge . . = 1·6 feet (about).
Length of bore . . . = 16·6 feet.
L = Travel of shot . . = 15 feet.
w = Weight of shot . . = 800 lbs.
v = Muzzle velocity . . = 1400 feet per second.
Rifling commencing at 1 turn in 438 calibres, concluding at 1 turn in 35 calibres, equivalent to 1 turn in 36·45 feet.
P = Total pressure in tons per square inch on the shot.
p = Mean pressure in tons per square inch on the shot.
f = Acceleration or retardation in feet per second.
g = Acceleration of gravity 32·2 feet per second.
k = Radius of gyration of shot in feet.

7000 grains troy . . . . = 1 lb. avoirdupois.

$$\text{Ratio } \frac{\text{Shot}}{\text{Calibre}} = \frac{800 \text{ lbs.}}{122 \cdot 7} = 6 \cdot 55 \text{ lbs. per square inch.}$$

The first column in Table I. gives the length of bore 16·6 feet, of which 1·6 are occupied by the cartridge, leaving 15 feet as the length which the shot travels in acquiring a muzzle velocity of 1400 feet per second. The second column gives pressures in tons at each foot in the gun, ascertained by means of Crusher gauges. The third column gives observed velocities, at positions corresponding with the different pressures, and the fourth column shows the differences between those velocities—that is to say, it gives the rate of acceleration (f) which occurs as the shot travels on its course, till it leaves the muzzle; and it is the sum of all these accelerations which makes up the final velocity of 1400 feet per second. The fifth column is deduced from the second, and gives the mean between each of these pressures, which add up to 95·5; and this figure, divided by 15 spaces, shows an average pressure of 6·37 tons per square inch—observed pressure on the shot. It is important to remember that pressure produces velocity through increments of acceleration; and that velocity, as such, absorbs no pressure,

TABLE I.



Distance. FEET	Tons per Sq. In. TONS	Velocity. FEET	Acceleration FEET	Averages. TONS
0	23·8			
1	23·8			
2	22·5			22·5
3	19·9	137	533	19·9
4	14·2	670	244	14·2
5	11·6	914	127	11·6
6	7·0	1041	69	7·0
7	3·8	1110	55	3·8
8	2·9	1165	47	2·9
9		1212	40	2·6
10		1252	34	2·4
11		1286	29	2·1
12	1·9	1315	25	1·9
13	1·6	1340	21	1·6
14	1·3	1361	18	1·3
15	1·1	1379	16	1·1
16	·6	1395	14	·6
		1409		
COLUMN 1	2	3	4	5

FIG. 1.

but alterations in the rate of acceleration absorbs all the pressure, and this rate may be taken as a maximum when the shot *begins* to move from a state of rest.

The rate of acceleration thenceforth diminishes, until it becomes zero, when the shot has acquired a full muzzle velocity and quits the gun.*

In considering the pressures most desirable for propelling a shot, with any given muzzle velocity, it is only necessary, therefore, to take note of the incidence of those forces which go to produce acceleration, for the mean pressure is fixed by the laws of dynamics, and cannot be altered.

The pressures from Column 2, Table I., are laid down like an indicator diagram in Fig. 2, and they constitute important data ascertained from the 38-ton gun.

Curve of Pressure.

Here, in Fig. 2,

A, B, = the travel of the shot to a scale of $\frac{3}{20}$ inch to 1 foot (L = 15 feet).

A, C, = the total pressure in tons per square inch indicated by the letter P, and drawn to a scale of 20 tons = 1 inch.

A, G, = the space taken up by the cartridge, 1·6 feet in the present example.

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* The whole theoretical argument by which this conclusion is justified will be found in 'A Practical Treatise on the Steam Engine,' by Arthur Rigg.

Ordinates upon A, B, represent pressures at every foot, and the curved line C, B, corresponding to those pressures, shows their variation and range, and gives an average of 6·37 tons per square inch, as shown by A, D, $= p$.

The total amount of energy is represented by the rectangle A, D, E, B, and the portion lying behind A as far as G is filled up by the cartridge, and represents an amount of pressure, much of which is lost so far as propelling is concerned. This space corresponds with the clearances in a steam-engine cylinder, and should be reduced to a minimum.

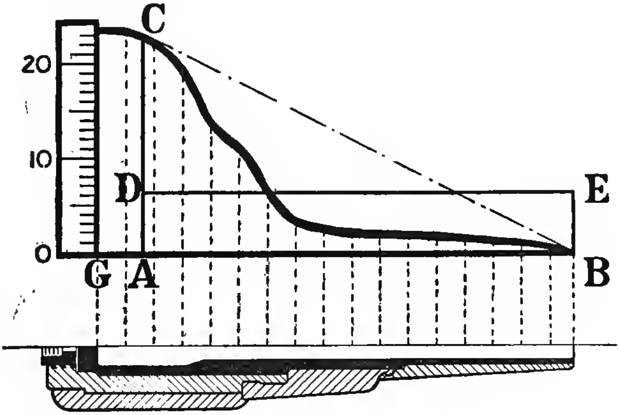

FIG. 2.

Whatever may be the exact sequence of changes which accompany the explosion of gunpowder, it is well known that only the smaller portion, or about 43 per cent. of the total products, become permanent gases, while the remaining 57 per cent. of inert matter assumes the form of a finely divided vapour, which is the well-known cloud of smoke accompanying the use of gunpowder. This large portion of inert matter occupies considerable space in the cartridge—space which has to be filled by vapour of the full initial pressure, and is no more than a sort of buttress against which the pressure acts which impels the shot, and in this capacity it is neither better nor worse than the base of the bore itself which costs nothing to fill.

Herein lies one advantage derived from the use of smokeless powder. As its cartridge takes little more than half the space of a gunpowder cartridge, giving equal propulsive power, so a correspondingly larger part of projectile force can be applied to the shot instead of filling up a vacancy which pure theory would altogether abolish.

In order to make the subject complete, it will be convenient to note that the average pressure in tons per square inch required for propelling a shot may be calculated according to the ordinary laws of dynamics by the following formulæ, using the symbolical letters already given on page 10.

$$\text{Mean pressure} = \frac{w \times v^2}{\text{A} \times \text{L} \times 2240 \times 2g} =$$

$$\frac{800 \text{ lbs.} \times 1400^2}{122{\cdot}7 \times 15 \times 2240 \times 2 \times 32{\cdot}2} = 5{\cdot}9 \text{ tons per square inch.}$$

This, then, is the mean amount required to give the shot a muzzle velocity of 1400 feet per second; but there must be added to it sufficient pressure for rotating the shot, expelling the air, and overcoming friction in the grooves, &c., so the results of calculation may be taken as being in close agreement with 6·37 tons, obtained by direct measurement; and these figures mutually tend to confirm each other.

Although all artillerists may not agree with the arguments and theories following, yet, so far as these figures are concerned, they are practically common ground, and it is only with the incidence of those varying pressures which make up this mean pressure that there is any room for differences of opinion.

So far as it appears by an inspection of Fig. 2, the pressure, commencing at 23·8 tons per square inch, and running down to ·6 tons (a variation of 40 to 1) indicates strains of a most irregular character—higher than needed for the commencement, and lower than they ought to be towards the middle and end of the travel.

◆

NATURAL LAW OF ACCELERATION.

It will now be interesting to inquire whether any natural law of acceleration prevails in other corresponding cases. Such a law we find in the movement of planetary bodies, in the acceleration of a train commencing to run up an incline, in the piston of a steam engine during the first half of each stroke, and in the acceleration of a stone from a sling.

The very earliest form of projectile would naturally be a stone discharged from a sling, and an examination of the laws involved in its operation gives a clue for ascertaining the minimum pressures that must be provided for accelerating a shot to any desired muzzle velocity, should it be intended that the shot shall obey the same laws that govern

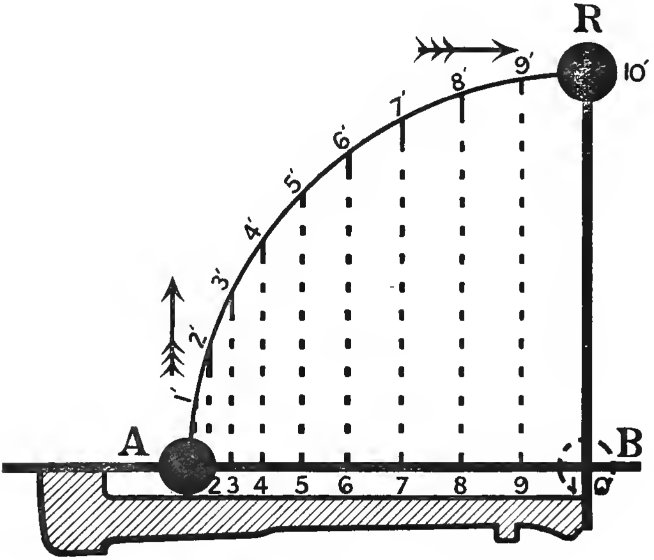

FIG. 3.

the operation and course of a sling-stone. Fig. 3 represents a stone R revolving round a centre B, at the radius A, B, and loosed at R. It would then travel along a tangential line with a circumferential velocity that may be designated by the vertical line R, B; the length of the arc A, R and spaces 1, 2, 3, &c., into which this arc is divided, representing equal intervals of time; for example, if A, R should be $\frac{1}{50}$ part of a second, then the several spaces 1, 2; 2, 3; &c., each represent $\frac{1}{500}$ of a second.

When the stone is passing the point A it is travelling vertically, and has no horizontal component to its motion—that is, component in the direction of A, B; but gradually its direction changes to one parallel to A, B, with the same velocity which it had perpendicularly when at A. The centrifugal force of the stone always acts radially, and is an exact measure of the initial pressure which would be required for giving a similar projectile at A its initial acceleration along A, B, in the direction of the arrow.

As a projectile is fired from the gun shown in half section, Fig. 3, it travels from A to B with a velocity variable, but increasing by increments of acceleration until the maximum amount, represented by B, R, on a vertical scale, is reached. The necessary force absorbed by acceleration meanwhile grows smaller and smaller by irregular decrements, until at B it vanishes altogether. If the full length of the line A, B be taken at any suitable scale to represent this initial accelerating pressure, ascertained by calculation, then pressures corresponding to successive equal periods of time are given on the same scale on A, B by perpendiculars drawn upon it as shown by dotted lines in Fig. 3, starting in every case the measurement from B to the point marked 5, 7, 9, &c., where the perpendiculars fall from 5,′ 7′, 9′, &c.

These lengths are brought down to a uniform base in Fig. 4, and their terminations will be found to lie in a diagonal line, L, B, which represents a gradual and regular diminution of the impelling forces from a maximum to zero.

Thus ordinates from A, B, drawn up to the diagonal line L, B, give exact measurements of the uniformly diminishing pressures required to produce acceleration according to the system which prevails with a sling-stone.

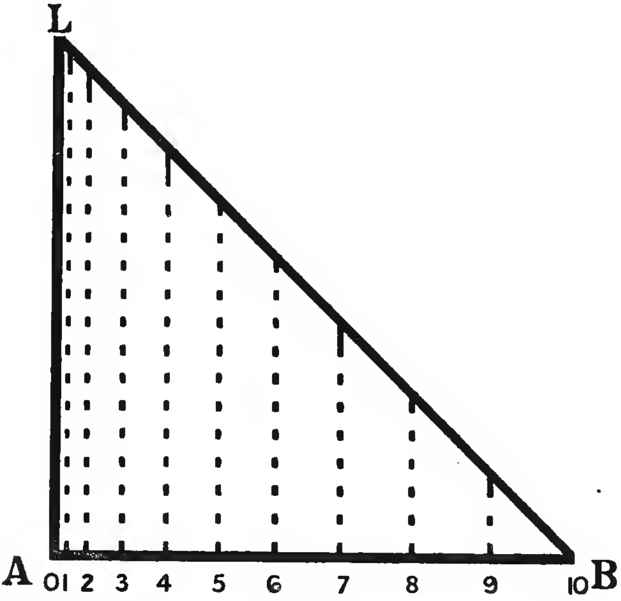

FIG. 4.

These Figs. 3 and 4 portray the operations of a natural law, which indicates how the highest possible velocity can be obtained with the lowest initial pressure, and with some regard to the economical application of power, expansion, and continuous burning, as contrasted with a sudden explosion. This somewhat new view of the question may very properly be tested by application to the pressures and velocities of a shot during its travel in a gun.

Presuming the shot to follow the same sequence of accelerations as a sling-stone, it will be found that the considerations determining the strength of the sling are exactly the same as those to be applied to the component parts of a gun.

If a shot of the same weight as the stone at R were discharged with the same muzzle velocity after travelling along a gun of the length A, B, then the maximum pressure that would be necessary for imparting the first acceleration would be found equal to the centrifugal force at A, and this pressure would diminish by regular instalments to zero, when the shot is discharged at B with its muzzle velocity complete.

The centrifugal force of any revolving body may be calculated from the formulæ:—

$$\text{Centrifugal force} = \text{weight of body} \times \text{revolutions per minute}^2 \times \text{radius in feet} \times \cdot000341.$$

The shot travels from A to B, and its muzzle velocity is assumed equal to B, R, being the same as that of the sling-stone discharged at R.

Here divisions 1, 2, &c., upon the quadrant A, R, represent, as before, equal intervals of time, and may be plotted down upon A, B, as in Figs. 3 and 4, for illustrating the pressure upon the shot at any part of its travel along the gun.

By adopting these general principles, and assuming any desired muzzle velocity, it is easy to ascertain by a graphic method, assisted by a very simple mathematical formulæ, the pressure required for acceleration, also the rate of acceleration, and the actual velocity which the shot possesses at any point of its travel.

The calculation can also be reversed for the purpose of ascertaining the muzzle velocity for any given powder pressure.

As it is very convenient to reduce all calculations of this kind to a common basis for comparison, the shot may be considered as weighing so many pounds per square inch upon its base.

The initial and average powder pressures, whether in rifles or heavy guns, will also be worked out in terms of tons per square inch.

The principles so far, as already stated, apply to smooth bores, but when rifled ordnance is concerned, it is obvious that some additions must be made to provide for rotating the shot, expelling the air, overcoming friction, and other minor resistances.

A little examination, however, shows that these extra resistances sink into insignificance as compared with the forces required to give the necessary muzzle velocity, and they may best be taken in order, beginning with the effects of rifling.

RIFLING.

Whether rifling is carried out with an increasing pitch or not, its final effect is the same in producing rotation at the rate of so many turns in a second of time; and the mean force is applied at some radius and not at its periphery.

This radius is the "radius of gyration," and is illustrated by the end elevation of a conoidal shot, Fig. 5. Here S, T represents the radius of a rifled shot, and T, V its corresponding radius of gyration, this being approximately $\frac{2}{3}$ S T = K.

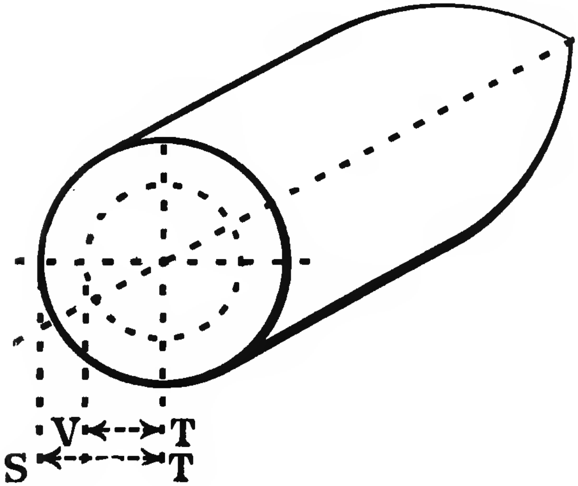

FIG. 5.

If the pitch of rifling be uniform, its rotation takes place by the very same increments of acceleration as those by which the shot itself acquires velocity; but this is not the case with an increasing pitch.

An engineer constructing a railway, and desiring to change from a level to a gradient, would never begin at the full inclination, but would make its commencement gradual, according to a parabolic curve or the arc of a circle whose centre is high up in the sky.

This corresponds exactly with an increasing pitch, and for similar reasons the designer of a gun adopts that system in order to lessen the excessive strain caused by a too sudden evolution of powder gases.

Whenever the powder pressure exceeds the natural requirements of a shot, the rifling adds an extra strain upon the already excessive pressure required for starting it, and that too upon a part of a gun already severely loaded to compensate for deficient pressures later on.

Uniform pitch thus produces a higher initial rotation than would be necessary if every inch of the bore took its proper share in giving the final muzzle velocity.

The first elements of an increasing pitch are therefore made almost parallel with the axis of a gun, and the greatest strain of rotation is postponed so as not to coincide with the greatest initial pressure for impelling the shot, for this occurs just at the commencement of its travel.

Increasing pitch is therefore nothing else than a compensation for any powder that gives an excessive initial pressure, and it transfers the strain of rotation from the breech towards the muzzle of a gun.

It is thus only permissible to have a uniform pitch when the shot can be started at so moderate a speed, and by such moderate pressure that its projection and rotation shall follow the sequence of some such law as prevails with the acceleration of a sling-stone, and with this latter system alone it would seem that increasing pitch can be abandoned for uniform pitch.

PRESSURE REQUIRED TO ROTATE A SHOT.

General Particulars.

Taking an illustration from the most complete series of experiments published, namely, the 38-ton Armstrong gun, page 11, its rifling has increasing pitch from 1 turn in 438 calibres to 1 turn in 35 calibres, or 36·45 feet at the muzzle.

The diameter of the shot . = 12·5 inches.
Its circumference . . . . = 3·27 feet.
Its weight . . . . . . = 800 lbs.
The velocity of its circumference . . . . } $= \frac{1400' \times 3\cdot27}{36\cdot45'} = 125\cdot7$ feet per second.

Assuming the radius of gyration upon which pressure acts, as being $\frac{2}{3}$ that of the shot,

The velocity at its radius of gyration =

$$\frac{2 \times 125\cdot7}{3} = 83\cdot8 \text{ feet per second;}$$

the mean pressure per square inch on base of shot to produce this rotation =

$$\frac{w \times v^2}{A \times L \times 2240 \times 2g} =$$

$$\frac{800 \times 83 \cdot 8^2}{122 \cdot 7 \times 15 \times 2240 \times 64 \cdot 4} = \cdot 02 \text{ tons per square inch,}$$

an amount so small that it may practically be neglected in comparison with the forces required for propelling the shot.

FRICTION.

The co-efficient of friction differs according to the nature of surfaces and varies from $\frac{1}{10}$ to $\frac{2}{10}$ for metallic surfaces in contact.

The liquid products of ordinary gunpowder possess certain lubricating properties, but this is not so with smokeless powders, as at present constituted. It may therefore be assumed that a higher co-efficient of friction must be reckoned for with the new powders.

Taking however $\frac{2}{10}$ of the weight as the co-efficient of friction, this shows a pressure of 800 lbs. × ·2 = 160 lbs., very little more than 1 lb. per square inch of the area of the bore, an amount that may very well be neglected when dealing with many tons or corresponding areas.

Comparison between Results Observed and Calculated.

Having now obtained experimental and theoretical results concerning those forces which act within a gun, it will be convenient to make a comparison and research as to the information that can be derived from these particulars.

Here the graphic method of calculation will facilitate the investigation, and prove more instructive also than tables of figures.

The various pressures tabulated on Fig. 1 are laid down, like an indicator diagram of a steam-engine, in Fig. 2, and re-arranged according to the general ideas explained, in connection with Fig. 3, in another diagram, Fig. 6. Here the horizontal line A, B gives the travel of the shot (15 feet) to the lower scale into which it is divided.

Where vertical ordinates from A, B, intersect the curve of velocity, their lengths from A, B, vertically represent velocities at given points, to the scale of velocities on B, R.

The same horizontal line A, B is also used to another special scale, to show tons per square inch upon the base of the shot; so where vertical lines from A, B, cut the curve of pressure, the length measured from B, R, gives tons per square inch on the horizontal scale, while corresponding velocities in feet per second are given by vertical lines as shown, dotted across to the vertical scale, B, R.

It can hardly fail to be noticed how in this diagram the curve of velocities very closely approaches the quadrant of a circle, and this agrees with the corresponding ideas represented by Fig. 3.

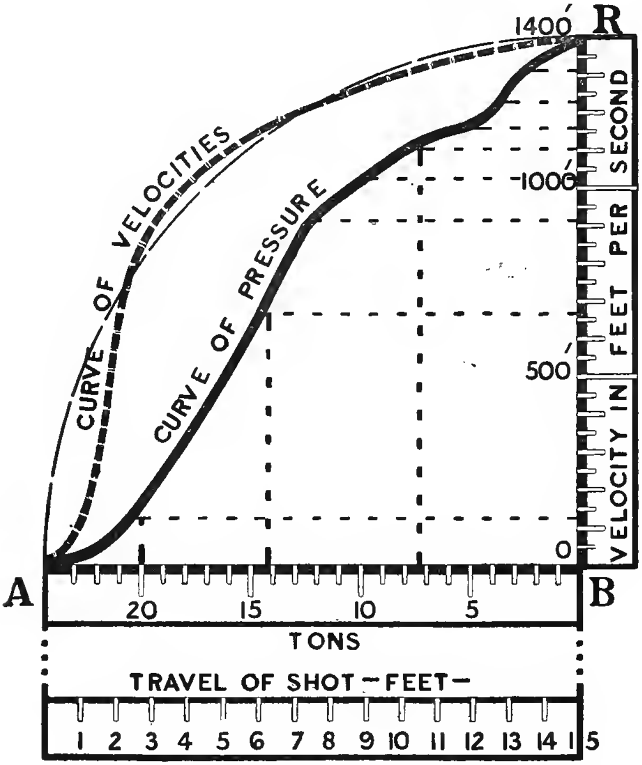

Fig. 6.

Results.

By experiment it appears that an initial pressure of 23·8 tons per square inch is given to the shot for its original acceleration; although by calculation it turns out that half of this pressure, or 12 tons per square inch, would have been sufficient. At 5 feet 6 inches of the travel, being about half the time during which the shot is in the gun, the pressure ascertained by experiment agrees with that calculated by this theory, but at half the travel the pressure is only 2½ tons, whereas it ought to be the mean, or 6 tons.

Thus 5 feet 6 inches of the gun is overstrained in order to make up for want of pressure during the remainder of its length. For this reason an excess of metal is required towards the breech, as commonly shown by the guns at present in the English service, but the new French guns for smokeless powder are stronger towards the muzzle, and better proportioned towards the breech. The highest initial pressure given by the Crusher gauge in this experiment was 23·8 tons per square inch, and if this were to follow the fine dotted line C, B, Fig. 2, it would represent an average pressure competent to impart a muzzle velocity of 2094 feet per second.

The conclusion, therefore, is that to secure a velocity of 1400 feet, this particular gun was subjected to an initial strain that would have sufficed, if properly followed up, to produce a velocity of 2094 feet per second. Fig. 7 is a diagram similar in general design to Fig. 6; but in this the initial pressure is taken as 12 tons per square inch by using a different scale for tons, but the same scales for travel in the bore and for acceleration and velocity. In Fig. 7 the same muzzle velocity is given and the same sequence of pressures is followed as that which prevails with a sling stone.

Both the curves for pressure and velocity are drawn so as to coincide accurately with the quadrant A, R. This quadrant also represents the total time the shot remains in the gun, and its equal divisions represent equal fractions of a second. This diagram therefore supplies the following different classes of information :—

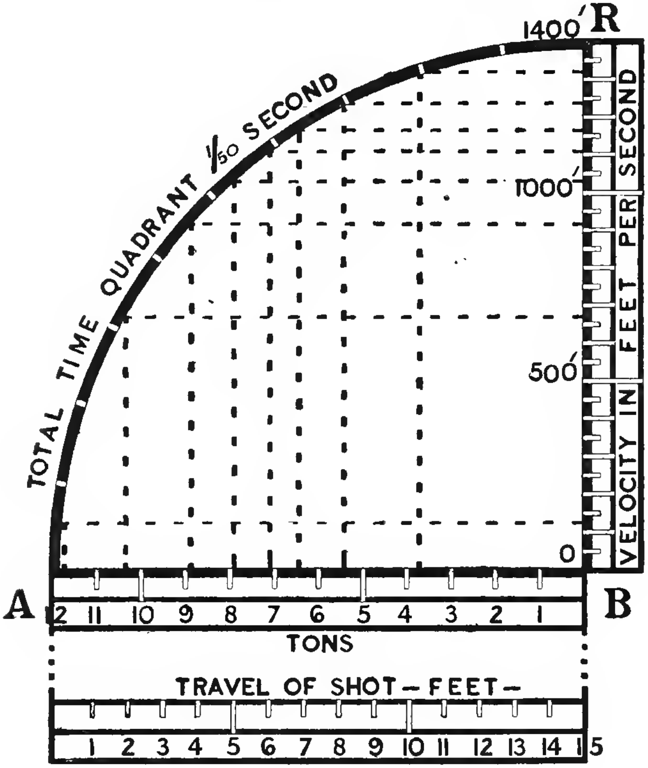

FIG. 7.

1. *Muzzle Velocity* = 1400 feet per second.

2. *Accelerated Velocity* = a maximum from the commencement to zero at termination.

3. *Proper Pressure* per square inch at commencement and throughout travel of shot.

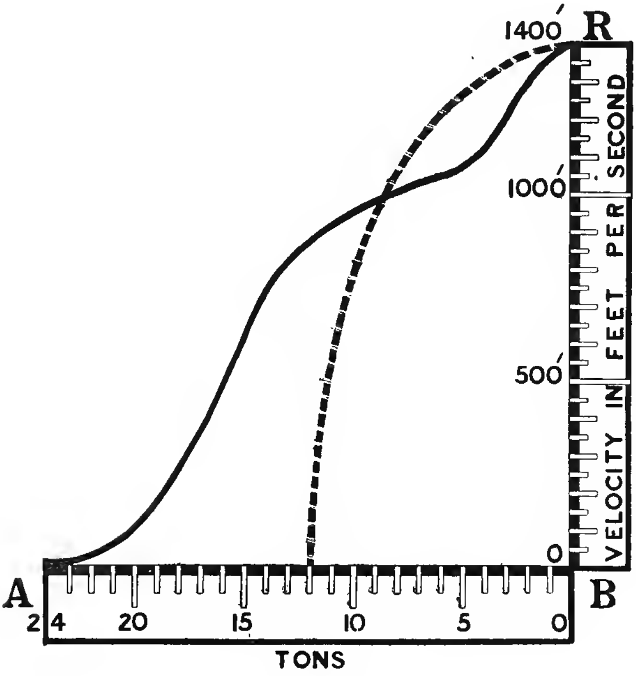

Fig. 8.

4. *Position of Shot* at any fraction of time during its travel.

As the tons in Figs. 6 and 7 are drawn to different scales, they do not very well represent their real differences at a glance, so they are repeated in Fig. 8, and both drawn to the same scale; so, by comparing Figs. 6 and 8, it now becomes easy to see how much greater strain is put upon the gun than is necessary to do the resulting work.

Foreign Guns.

Very few particulars are published as to the performances of foreign guns, and the data given never seems to be sufficient for working out complete results. It is not, therefore, by any means easy to make proper comparison between the different ideas embodied in their construction and in those which prevail among ourselves.

The present fashion tends rather towards the production of guns of abnormal length, and as length figures in the denominator of the equation, by which the mean pressure to propel a shot at a given muzzle velocity, is ascertained; it follows that this pressure might be expected to reduce in direct proportion to the length of a gun. Consequently, when the highest workable pressure has been reached, beyond which the materials at disposal can endure no further strain, there would seem no simpler way for increasing the velocity than by elongating the gun. This, however, cannot be carried very far without producing a weak unwieldy weapon, one in which an excessive vibration becomes set up towards the muzzle; and this not only damages the gun, but is prejudicial to all accuracy of aim. One cause of this excessive vibration in long guns is not far to seek, and it arises from the unbalanced rotation of a shot. All rotating bodies tend to rotate round their centre of gravity, so that unless a shot is truly balanced about the centre line of its longitudinal axis, it will rotate around some other centre, and thus become an excentric mass rotating at a high speed, and setting up vibration of an intensity that grows rapidly with the rate of its rotation, and that increases with the length of the gun. If for no other reason than this, artillerists will find the utter uselessness of carrying length too far in a gun,* unless, indeed, they are prepared to balance every shot and shell round its larger axis. This element of vibration is so uncertain in the periodicity of its operation, or in the duration of its effects, that it cannot be made the subject of exact calculation; because nobody knows what accidental vibrations may accompany the want of balance in each particular shot.

It would be very costly to balance every shot, and absolutely impossible to balance every shell around its central axis; the only thing certain about the whole matter is that vibration means a waste of power in the shot, that it does much harm to the gun, and destroys all accuracy of aim.

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* It is a well-known fact that there are guns of long calibre in the British Service which have been permanently injured by vibration having caused the muzzle to drop; and this has happened even during the ordeal of testing such guns.

The inferences deducible from this argument seems to be that it is altogether unsafe to assume that pressure reduces without any limit in exact relationship to the length of a gun; and any theory accepted on this basis will be as misleading as theories usually are found to be when founded upon partial data, omitting all consideration of the encircling facts. Even accepting the cautions implied by this discussion, it will still be interesting to select some foreign guns for comparison, and to calculate the results obtained on the basis that the data given are correct.*

Thus it is only the assumption that the shot or shell used in certain experiments with guns of long calibre have been carefully turned and balanced, that the reported high accuracy can be secured.

Tolerably complete data have been published in 'Engineering,' concerning the performance of the French "Canet" guns, and of the designs adopted by the United States Government. Our own War Office have, with the greatest liberality, furnished exact data of three important and representative guns, showing the most recent practice in the British Service (1892).

Table 3 gives these results in a simple accessible

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* It is a curious fact that although guns are bored to gauges, with a limit of variation of $\frac{1}{1000}$ part of an inch, this exactitude is never maintained after a few trial shots are fired. It is a more curious fact that shot and shell for use in these same guns are not manufactured with any accuracy at all, but are roughly fitted to size by an ordinary grindstone, leaving the gas-check to do the rest.

TABLE III.—COMPARISON BETWEEN THE PERFORMANCES OF VARIOUS GUNS.

Name.	Calibre.	Length of Bore.	Weight of Shot.	Muzzle Velocity.	Initial Pressure.	Powder Charge.		Calculations.		
						Black.	Smokeless.	Travel of Shot.	Average Press.	Initial Press.
	inches.		lbs.	feet.	tons.	lbs.			tons.	tons.
Armstrong 38-ton	12·5	16·6′	800	1400	23·8	130	..	15′ 0″	6	12
Armstrong 5·5 ton	6	20	100	2339	..	38	..	18·5	7·25	14·5
Canet 15 c/m. .	5·9	30 Cal.	188·18	1640	..	..	..	12·5	4·8	9·6
" ". .	5·9	40 "	..	2165	..	..	..	17·5	5·9	11·8
" ". .	5·9	50 "	..	2559	..	..	..	22·5	6·5	13·0
United States .	8	21·33′	300	1935	16	14·31	..	17·65	8·8	17·6
" " .	10	29·23′	575	1953	16·6	..	..	24·8	7·8	13·6
Maxim . .	3	..	14	2100	..	7 lbs. 2 ozs.	..	9·18′	6·66	13·32
Nordenfelt . .	3	..	14	2455	14·75	..	2 lbs. 12 ozs.	9·18′	9·102	18·20
" . . .	1·85	..	3·3	1920	..	1 lb. 8 ozs.	..	5·93′	5·281	10·56
" . . .	1·85	..	3·5	2284	12·25	..	12 ozs.	5·93′	7·486	14·97
6-inch BL. . .	6·00	..	100	1960	..	48 EXE.	..	10·92	8·87	17·74
9·2 BL. . . .	9·20	..	380	2036	..	166 Prism. Brown	..	20·56	7·99	15·98
13·5 BL. . .	13·50	..	1280	2016	..	48 EXE.	..	31·59	7·97	15·94

form; and it will be observed that no data are given with smokeless powders, as in the present somewhat experimental state of this class of explosive, the results might be subject to considerable future modification.

These examples may serve to show partly what is expected from the guns by their designers, as some of the data given appear to have been obtained by calculation and not by direct experiment. Such of these data as are useful for the present inquiry are given in the subjoined Table III., together with corresponding data from the 38-ton Armstrong gun for comparison.

The last three columns are obtained by calculation, and they give the travel of shot, and the initial pressure. These initial pressures are in every case taken as equal to twice the average, and this gives the rate of acceleration similar to that already explained on page 16, in connection with Fig. 3.

It will be seen that the Armstrong 5·5 ton quick-firing 6-inch gun, with a muzzle velocity of 2339 feet per second, requires an average of 7·25 tons per square inches initial pressure, while the "Canet," 15 c/m gun of 5′ 9 inches diameter, which is practically the corresponding French size, requires 4·8, ·5·9, and 6·5, tons per square inch, according to length, to propel a shot 1640, 2165, and 2559 feet per second, respectively; this velocity increasing in a higher proportion than length of calibre. From the United States trials, it would appear that their

8-inch gun, carrying a 300 lbs. shot, with a muzzle velocity of 1935 feet, requires 16 tons per square inch of black gunpowder, or 14·3 tons with smokeless powder, but as the smallest possible initial pressure required to accomplish this work is 17·6 tons, excluding whatever power goes for rotating the shot, it is evident that the data quoted are wrong somewhere.

The United States 10-inch gun, having a 575 lb. shot, discharged at 1953 feet per second, is stated to require 16·6 tons initial pressure, and as calculation gives 15·6 tons without considering the rotation of the shot, this experiment may be nearly correct.

An interesting series of examples are given at the end of Table 3. These are the most recent English guns, 6 inch, 9·2 inch, and 13·5 inch, and the data have been liberally furnished by the authorities at the War Office. From these data it has been calculated that the maximum initial pressures to impel the shot, leaving out of consideration all that goes for rotation, etc., are 17·74 tons, 15·08 tons, and 15·94 tons respectively.

These proportions show diminishing pressures combined with increasing bores, and this points towards an approach to some regular and systematic principles having been considered when designing these guns.

CONCLUSIONS AS TO GUNS.

If it were possible in actual practice to get a full theoretical result out of an explosion of gunpowder, in exact accordance with the system of acceleration suggested, then ordinates to the diagonal line L,B, in Fig. 2, would represent the exact pressures at every point required to produce the characteristic curve of accelerations represented by vertical ordinates from a base line A,B, to the quadrant of a circle A,P, in Fig. 1. But such a purely theoretical result is not even wholly desirable, even if it were possible in practice. For example, it would not be worth while to expand the gases down to atmospheric pressure, as the gain by doing this would require an inconvenient addition to the length of a gun, which is very objectionable for reasons already explained.

The powder pressures, therefore, should never be fully exhausted when the shot leaves the gun. Again, supposing a theoretically perfect result were attainable, it would become necessary to provide special powder for every kind of gun, and this is plainly out of the question. So long as small arms and heavy guns of different calibres are used in the service, there must of necessity be some difference in the powders; and how to balance the advantages and disadvantages of any desired compromise is a difficult and yet unsettled question. In any case, it would seem that there must be at least three kinds:

one for rifles or machine guns, another for field artillery, and yet another for heavy ordnance.

Everything, therefore, that can be considered practically possible with any theoretical proportions adopted, is to accept a sequence of pressures, with its corresponding rates of acceleration as a general guide only, and then to make the best possible approximation to this, or, indeed, to any system which may be accepted as a standard.

The foregoing illustrations and arguments therefore indicate rather the thing to be sought for in all explosives used for guns then, as giving results that should be implicitly followed under all conceivable circumstances and conditions.

As the composition, rate of combustion, and mechanical condition of the new smokeless powders can be varied to suit any desired rate of explosion, it falls naturally into the business of the powder manufacturer to suit his productions to the need of the guns, instead of expecting the guns to be made to suit the powders.

By accepting the law of acceleration due to a regularly diminishing pressure as being most simple in all relationships, and especially for guns, it only becomes necessary to provide an initial pressure which should be double that of the mean pressure, and this initial pressure gradually falls to zero, as shown by the sloping line C, B in Fig. 2, or the curve A, R in Figs. 3 5, 6 and 7.

Supposing all the charge to be exploded into permanent gases before the shot commences to move, then its initial pressure would rise far above twice the average pressure, and it would fall according to a curve approximating to a hyperbola much like the expansion curve in a steam engine indicator diagram.

Such a powder could never give a curve at all approaching the sequence of pressures suggested as a standard, but there is a way remaining open by which this can be done, namely, by using a powder that continues to burn all the time, and does not complete its combustion until the shot is at the point of leaving the muzzle.

It would seem best that this ideal powder should have its rate of combustion controlled in some degree by the pressure under which such combustion occurs, and, just as a candle burns quickly under ordinary pressure, and very slowly in compressed air, so should the explosive burn quickly until the space occupied by the cartridge reaches the intended initial pressure, when the combustion is slowest, and gains in rapidity as the pressure reduces during that fraction of a second while the shot is travelling in the bore.

By this means each foot length of the gun bears its full proportionate share in resisting the forces needed to propel a shot at its highest muzzle velocity, till the limit of endurance is reached, and we obtain the lightest possible gun for giving the best results in firing. It may be said that these are conclusions by no means new; but it may well be asked how many years have been necessary to find them out, and how many costly failures have been made to prove what these diagrams and simple calculations show so clearly and so well. The tabulated statements of modern gun practice show that no recognised standard or orderly system yet exists; everything seems to be done haphazard, and it is in the hope of doing some little towards evolving order out of chaos, that this memorandum has been compiled.

Note.—Recently a diagram has been published by Captain Noble, contrasting the curves of pressure, velocity, and time, ascertained from the same gun when firing Pebble Powder, Amide, or Cordite. These powders gave maximum pressures of 16·4 tons, 16 tons, and 14·4 tons respectively; and corresponding muzzle velocities of 1839 feet, 2036 feet, and 2150 feet.

His curves, rearranged on the same principle as Fig. 6, produce most instructive diagrams, and tend still further to confirm the conclusions arrived at by considerations drawn from the behaviour of the 38-ton gun tested under similar conditions.

PART II.

MODERN EXPLOSIVES.

Modern explosives for purely military and naval purposes may be classified under two heads, namely—

(1.) Explosives for use in guns.

(2.) "High explosives," for charging mines, filling shells, &c.

Up to recent times, gunpowder stood alone under the first heading, while all under the second heading were too violent in their operation, and could only be used for mines, torpedoes, &c.

Gunpowder represents a class of explosives, not chemical compounds, but wherein the materials are mixed in something like their combining proportion; and attempts to construct a new explosive on this principle have not been very successful.

One mixture, known as "Amide" powder, or "Chilworth special," has the sulphur of gunpowder replaced by ammonium nitrate, and its explosion gives a considerable increase of permanent gases, with a corresponding rise in potential energy.

The diminished quantity of gritty solid particles, grinding along the bore after an explosion, implies a lessened erosive action from this, or indeed any other powders convertible into permanent gases, in contrast with gunpowder, and its 57 per cent. of permanent solids; and experiment fully confirms this inference.

But there is a fatal objection to "Amide," and all other powders containing ammonium nitrate as their basis, because of its deliquescent character, an objection which detracts from its value as an otherwise useful ingredient of smokeless powders also.

One of the first high explosives discovered was guncotton, and although many attempts were made to adapt it to firearms, no satisfactory results ever came from these experiments.

A variety of other explosives were tried, wherein picric acid, nitrate of ammonia, or other compounds containing nitrogen formed the basis, but their chemical reactions were not until lately under sufficiently reliable control, and the explosives acted far too rapidly for use in guns.

Various forms of nitro-glycerine were equally unsuccessful, and this powerful explosive had to be mixed with infusorial earth under the name of "dynamite," to render it manageable, and moderately safe, even for blasting purposes in mines.

Curiously enough, however, this violent explosive, when mixed—or more properly combined—with some other violent explosives, actually has the effect of producing a compound which is less violent in its action than either ingredient alone!

Modern chemistry, however, has now discovered that the rate of combustion in some of these more violent explosives can be reduced and so modified, that their action is far less injurious to a gun than is that of black gunpowder. Indeed, these modifications can be carried so far, that any desired rate of explosion can be had. Thus a new and most important series of combinations became available, whereby the pressures can be arranged to suit any requirements in a gun, and there remains no longer any necessity for designing the gun to suit an excessive strong powder, instead of considering the most serviceable construction, in regard to the requirements of a gun.

Explosives to give little vapour, and that of a character soluble in air, are of such universal interest, that it is not surprising to find numerous patents taken out for all kinds of changes, improvements, or possibly retrogressions in the processes of manufacture ; but it would be impossible to notice these without extending this memorandum beyond all reasonable limits ; and perhaps it would be invidious to select a few out of so many inventions, some of which can hardly have been thoroughly tested. There is, however, a consensus of opinion that guncotton, in the form of tri-nitro-cellulose in combination with nitro-glycerine, is the most promising of all compounds for the production of a suitable powder. Therefore most inventors have turned their attention to improvements in the details of its manufacture, particularly to the thorough nitration of the whole mass and the avoidance of any excessive production of the insufficiently nitrated cotton or pulp, known to chemists as mono-nitro-cellulose or di-nitro-cellulose.

The highest form of nitrification called tri-nitro-cellulose, can only be produced in the presence of undiluted nitric acid, so that when cotton or pulp is added to the bath of nitric and sulphuric acids the earlier portions become a pure tri-nitro-cellulose, while later additions of cotton or pulp are found to yield a certain proportion of the lower and inferior qualities, owing to the nitric acid being diluted with water produced during the nitrification of the first instalments.

It is evident that an unstinted employment of nitric acid would accomplish a complete nitrification of the whole mass; but it would do this at an excessive cost, so the object of every inventor has been to use acids weakened by partial use for producing a confessedly imperfect nitro-cellulose which can then be fortified by admixture with new supplies of acids which, in their turn, can serve for the first stage of the process.

The same general arrangements will apply to the manufacture of nitro-glycerine where glycerine is used instead of cotton or pulp, and goes through a very analogous process.

Improvements in the process are made in another direction, by cutting up and grinding cotton or woody fibre into small fragments, so that the acid reactions do not become hindered in consequence of the protection afforded to the fibres by the hard or silicious skin in which they are generally enveloped. In addition to this coating, a gum or essential oil is present, and this is slow to dissolve, not always being completely removed by the alkaline washings to which fibres are subjected before the process of nitrification is commenced.

The removal of these difficulties, partly chemical and partly mechanical, are subjects of several patents which are intended to produce a nitro-cellulose of uniform composition, and ballistic qualities.

Strength of Various Explosives.—The strength of various explosives exhibits great differences, and probably the most violent and dangerous of all known to chemists is chloride of nitrogen ; but this substance is so easily disintegrated that it is perfectly useless for military purposes. Of all explosives based upon the use of a nitro-cellulose, the gelatinised compounds rank highest in their explosive qualities.

Then comes nitro-glycerine, followed in order by guncotton, dynamite, picric acid compounds, melanite, and gunpowder.

It may now be useful to give a short account of some of these explosives, and the modes of their manufacture.

Guncotton. $C_6H_7\ 3\ (NO_2)\ O_5$.

A very important modern explosive is guncotton, which is a nitro-cellulose obtained by steeping thoroughly dried cotton in a mixture of strong nitric and sulphuric acids. During the time when nitration is taking place, the sulphuric acid acts as an absorbent of all free water, together with that which is produced by the chemical reactions occurring during the process.

The resulting product is washed in water and alkalies, to remove all free remaining acids, and then converted into pulp by revolving knives.

This process was adapted to the manufacture of guncotton, by Sir Frederick Abel, F.R.S., Chemist to the War Department, and he also arranged hydraulic presses by which compressed guncotton was sent out wet or dry, according to its intended use ; dry guncotton burns rapidly in the open air, with a bright flame making no smoke, but only a thin vapour which dissolves at once in the air. Wet guncotton is not readily fired, and can only be exploded with a pistol and detonator.

Dry guncotton is not considered reliable in hot climates, in consequence of the development of nitrogen compounds, which cause spontaneous decomposition and explosion. This danger, however, is removed by keeping it constantly wet, and this is done in all magazines, whether in ships of war or ashore.

For all this, guncotton remains the safest of all high explosives, and it possesses the great advantage of being uninjured by time or exposure to damp unless it becomes mildewed.

Wood-pulp, or other vegetable substances, are used instead of cotton for manufacturing the large quantity of nitro-cellulose required for smokeless powders.

Curious variations occur as to the rate of combustion and other qualities in the explosive, when made from different kinds of woody fibre, and very little is understood as to the precise causes of such minor variations. Before the manufacture of guncotton or nitro-cellulose was thoroughly understood, several very disastrous explosions occurred ; and although in England the manufacture has now for many years been carried on with perfect safety, yet it does not seem as if sufficient precautions have always been taken abroad, as disastrous explosions are still occasionally reported.

Nitro-Glycerine.

Tri-Nitro-Cellulose = $C_3H_5(NO_3)_3$.

This explosive was discovered by Sobrero in 1847, and it is produced by adding glycerine, in small quantities at a time, to a mixture of one volume fuming nitric acid of a specific gravity about 1·43, and two volumes of the strongest sulphuric acid, of a specific gravity about 1·83.

Considerable heat arises during the mixture of these acids, so that they have to be cooled, and kept at from 40° to 90° Fahr. for the subsequent process.

Not until the acids are thoroughly cooled, is it safe to add, little by little, about 12 per cent. of their weight of syrupy glycerine. This mixture is constantly stirred, and the great heat developed by the chemical reactions must be absorbed by a coil of water pipes, by ice, or by other means such as freezing mixtures; so that on no account shall the temperature exceed about 105° Fahr.

This is the most dangerous part of the whole process, for any excessive heat would cause a violent explosion, with results disastrous in the extreme.

When further action ceases, the process is completed, and the nitro-glycerine floats over the surface.

The mixture is then poured by small quantities at a time, accompanied by constant careful stirring, into a bath of cold water. Although the nitro-glycerine floats on the surface of the mixed acids, its specific gravity is greater than water, in which it is practically insoluble, as the oil sinks to the bottom of its water-bath, and the upper layer of dilute acid can be removed by decantation or by a syphon.

The chemical reactions which occur during the formation of tri-nitro-cellulose, the most explosive form of nitro-glycerine, are as follows:—

$$\text{Glycerine } (C_3H_8O_3) + \text{Nitric acid } (3HNO_3) =$$
$$\text{Nitro-glycerine } (C_3H_5(NO_3)_3) + \text{Water } (3OH_2).$$

Thus it will be seen that in the process of nitrification the 3 parts of water forming its original composition are replaced by 3 parts of nitric acid; and there remains over the residue of water which is absorbed by the sulphuric acid.

The affinity of nitric acid for 1 part of the constituents of nitro-glycerine is assisted by the affinity of sulphuric acid for the other part, and this double influence is necessary to effect the reactions above described.

The nitro-glycerine is now washed again and again in fresh water, to remove every trace of remaining acid, and this process is continued until blue litmus paper shows no change of colour.

Pure nitro-glycerine can be obtained by crystallization from its solution in wood naphtha, but such a refinement is never necessary when the explosive is required for immediate use. Nitro-glycerine is a yellowish oily liquid, having no smell, and a sweet pungent taste.

It is so poisonous, that a tiny quantity placed on the tongue produces a violent headache lasting for many hours, cough, indigestion, and a general disturbance of the nervous system. These effects are doubtless produced from fine unconsumed particles of nitro-glycerine, which are scattered about after any explosion; and these evils are increased in mining operations, where the products of explosion are unable to get quickly mixed with large quantities of air. The asphyxia sometimes produced by nitro-glycerine or dynamite poisoning is probably due to, or accentuated by, volumes of carbonic monoxide, which comes from the chemical reaction. This dangerous gas is supposed to be absorbed by the red corpuscles in blood, and never discharged like oxygen; consequently, these bodies being saturated by one gas, cannot find room for the vitalizing agent, and asphyxiation follows as a matter of course. Nitro-glycerine is also readily absorbed into the system through the skin when handled, but, curiously enough, this peculiarity ceases after a time.

This liquid has a specific gravity of 1·6, and freezes solid at about 5° centigrade or 40° Fahrenheit, and explodes at about 360° Fahrenheit. It burns in the open air with a smoky flame, and can be readily exploded by concussion, and when frozen it is particularly dangerous, as mere friction will cause a disaster.

Another method has been patented for manufacturing nitro-glycerine, and it consists of a mechanical process, worked by compressed air, by which the acids and glycerine are made into a spray, and mixed in a sort of injector, the expansion of the air producing a lowered temperature, which counteracts the increasing temperature attending the mixture of acids and glycerine.

Nobel's Dynamite, No. 1 of commerce, consists of 75 per cent nitro-glycerine mixed with 25 per cent. of a very absorbent infusorial earth known as "Kieselguhr"; and Lithofracteur, another explosive, consists of 55 per cent. of nitro-glycerine and other substances in different proportions, all of which add to its explosive character, and it contains only a very small proportion of the inexplosive and incombustible "Kieselguhr." Blasting gelatine is practically a stage in the manufacture of smokeless powders, and it is composed of the soluble or collodion form of guncotton dissolved in nitro-glycerine.

In this curious chemical compound the nitro-cellulose becomes gelatinised, while the nitro-glycerine forms part of a more stable compound, and one that practically serves as the basis for all those smokeless powders which seem most likely to become the permanent substitutes for ordinary gunpowder.

Smokeless Powders.

Numerous compounds have been brought out as "Smokeless Powders," called in Germany "Smoke-Feeble Powders," as none are really smokeless, and their mode of manufacture has been surrounded by much mystery.

The whole problem, however, is one of comparatively simple chemistry, and mechanical manipulation, so that although the materials composing the chief smokeless powders are well known, yet minor details of manufacture are kept by various makers as trade secrets, and such matters are somewhat jealously guarded as they cannot be properly protected by patent. All smokeless powders are supposed to have nitro-compounds, or picrates as a base, but those most generally used are composed of a compound containing nitro-cellulose and nitro-glycerine.

The original "Nobel" powder is described as being composed of 10 parts by weight of camphor, dissolved in 100 parts by weight of nitro-glycerine. Then 200 parts by weight of benzole is added, and 50 parts of nitro-cotton pulp is steeped in the liquid. The mixture is then warmed to evaporate the benzole, which acts merely as a solvent, and the resulting compound is passed between steam-heated rollers, and the sheets so produced finally cut up into small squares or other shapes as required.

It was, however, found that camphor was unreliable, and the composition has been completely altered. It is rolled into thin sheets of a dark colour, and cut into strips and grains.

Nitrate of Ammonia is used as a basis in other smokeless powders, but it has the disadvantage of being deliquescent, so that it has to be made up into cartridges hermetically sealed, and these are constructed hollow, so as to provide an air chamber which lessens the violence of explosion.

Various other substances, such as picric acid, chloro-picrum, hydro-chlorate of ammonia, camphor benzole, nitrate of ammonia, nitrate of soda, nitrated carbolic acid, nitrate of potassium, hyposulphite of soda, and other alkalies, and many other substances, are used in the manufacture of smokeless powders or high explosives; but, so far as present experience goes, those compounds which have blasting gelatine as the first stage of their manufacture seem to meet with most general favour.

Cordite.

This smokeless powder was invented by Sir Frederick Abel, F.R.S., Chemist to the War Department, in conjunction with Professor Dewar, F.R.S., of the Royal Institution, London, and other eminent chemists, and it has been made in considerable quantities at the Government powder factory at Waltham Abbey, and by the Chilworth Company, and also in Germany.

The chief ingredient in its composition is guncotton, or nitro-cellulose, and this is mixed with nitro-glycerine, with the help of a solvent.

Other substances are added, whose function is to tone down and determine the rate of combustion, so as to fit the resulting explosive for use in guns.

When the ingredients have been thoroughly mixed and incorporated (just as gunpowder is incorporated) they become a pasty mass, which is placed in a circular chamber having holes in its lower end; hydraulic pressure is applied, and the mass is squirted in the form of thick jelly into strings, whose diameter is determined by that of the holes.

These strings are collected upon a reel, rapidly dried by steam, and finished by being cut to the length of the intended cartridge, tied together into bundles, and placed into the cartridges; all these operations being performed by self-acting machinery.

The rate at which Cordite explodes depends in a great measure upon its diameter, and thus one uniform composition may give great varieties of pressure according to its mechanical state alone, and this is a very important consideration.

The effect of Cordite in accelerating the muzzle velocity of a shot is well shown by the following table, supplied by the Maxim Nordenfelt Company, being experiments made on their own guns.

Description of Gun.	Bore.	Projectile.	Black Powder.			Cordite.			Calculations, Mean Pressure.	
			Charge.		M. V.	Charge.		M. V.	Black Powder.	Cordite.
	inches.	lbs.	lbs.	ozs.	feet.	lbs.	ozs.	feet.		
14-Pr.	3	14	7	2	2100	2	12	2455	7·309	9·102
3-Pr. .	1·85	3·3	1	8	1920		12	2284	5.281	7·486

In both cases higher results are secured by $\frac{1}{3}$ and $\frac{1}{2}$, the weight of explosive respectively, as compared with black or brown gunpowders.

The initial pressures were not ascertained, but they will doubtless be less in either case than the corresponding pressures with black gunpowder.

In the 15th Annual Report of H.M. Inspectors of Explosives for 1890, page 80, the following experiments are described. They were undertaken to determine the liability of Cordite to explode *en masse*, on October 21, 1890, and were carried out in the presence of the Director-General of Ordnance

Factories, H.M. Chief Inspector of Explosives, and other officers :—

"(1) 100 lbs. of coarse Cordite (3 inches in diameter and 14 inches in length) packed in a service box (measuring 2 feet 3 inches by 14 feet 6 inches by 7 feet 9 inches deep, and having 1¼ inch sides and 1 inch top and bottom), was attempted to be ignited by means of a tube and small priming charge of guncotton. But the Cordite failed to ignite.

"(2) Repetition of above, but using a small priming charge of fine Cordite (·05 inches diameter and 11 inches long). The whole mass burst immediately into flame, and burned with great and rapid energy and brilliancy. The lid was removed by the energy of the outburst, the screws being drawn, and those on one end bent. The mass burned for about three seconds, and the light was of the most brilliant character.

"(3) Repetition of No. 1, with same result—no ignition.

"(4) Repetition of No. 2. The Cordite ignited and burned with great brilliancy and a gush of bright flame for about 7½ seconds. The lid of the box was forced off (as in No. 2), and the screws were drawn, and in some cases bent.

"(5) A service case (of dimensions previously given) containing 100 lbs. of the fine Cordite was surrounded by wood and shavings, which were set fire to. The bonfire burned for 15 minutes, when the Cordite in the case ignited, and burned with a great rush of most brilliant flame for about four or five seconds. Some small pieces of the burnt wood were then thrown to a distance of about 12 yards. An end of the box was forced out. One side was partially forced out.

"(6) Repetition of No. 5, but using fine instead of coarse Cordite. After the bonfire had been burning for seven minutes, the Cordite caught and went off with a dull, muffled burst which nearly amounted to a mild explosion.

"There was, however, certainly nothing approaching a violent explosion, as was shown by only one side of the box being displaced.

"(7) Six service boxes, each containing 100 lbs. of thick Cordite, were placed together, five on end and one on the top; the centre box (in lower tier) was set fire to. It burned about six seconds, and upset the side boxes, but it did not throw off the top box; only the box which was ignited caught fire.

"(8) Five service boxes, each containing 100 lbs. of thick Cordite (*i.e.* those which remained from the last experiment), were placed in a pile, two, two, and one, breaking joint, and surrounded by wood and shavings, which were set fire to.

	Mins.	Secs.	
After	15	0	. . . . 1 box of Cordite ignited.
"	15	7	. . . . 1 " "
"	15	14	. . . . 1 " "
"	15	21	. . . . 1 " "
"	15	28	. . . . 1 " "

"Each box burned with a bright rush and burst of flame, but without explosion. The boxes were not broken up, and no fragments of the bonfire were projected beyond about 10 paces.

"(9) A pile of eight service boxes, containing each about 75 lbs. (total 600 lbs.) of Cordite, was surrounded with wood and shavings, which were set fire to. The top box had a hole in it, which was roughly plugged, and this apparently caught fire and burned away non-explosively at 1 minute 10 seconds after the bonfire had been ignited. The other boxes ignited in succession and burned away non-explosively. The times were as follows :—

	Mins.	Secs.		Mins.	Secs.
1st box . . .	1	10	5th box . . .	17	25
2nd " . . .	1	15	6th " . . .	18	37
3rd " . . .	2	2	7th " . . .	21	31
4th " . . .	5	45	8th " . . .	21	33"

Satisfactory results are also given by Cordite as used in rifles, and this may be seen from the following recent letter referring to results obtained from firing in June 1892. This letter is a reply to an inquiry as to whether the new smokeless powder, "Cordite," is giving satisfaction :—

Dear Sir,—In reference to your inquiry as to whether "Cordite" powder is giving satisfactory results, I am desired by Mr. Stanhope to inform you that the military authorities are well satisfied with our new smokeless powder. The following table bears testimony to the reliable quality of "Cordite" powder.—I am, dear Sir, yours truly,

G. FLEETWOOD WILSON.

WAR OFFICE.

ALDERSHOT DIVISION.

Return of ·303 Cordite ammunition, showing the number of rounds expended, and number of miss-fires that occurred during the month of June, 1892 :—

Corps.	No. of Rounds expended.	Miss-fires.
1st S.W. Borderers	42,300	17
1st Durham L.I.	30,731	19
2nd Leinster	25,322	8
1st Scottish Rifles	19,140	4
1st Northampton	62,760	43
2nd Welsh Regiment	10,949	13
1st R. Lancaster	21,493	29
1st R. Warwick	38,594	Nil
1st Lincoln	26, 61	47
2nd S. Stafford	25,560	4
Total	303,110	184

Miss-fires ·60 per 1000.

The following extracts from a paper read before the Royal United Service Institution, in July 1891, by Lieutenant-Colonel G. V. Fosbery places the views of a thoroughly competent expert in a concise and telling form :—

"At present, so far as is known to me, we are still in search of the ideal explosive; one, in fact, which shall pack into the smallest possible space, develop the utmost energy, and keep indefinitely under all possible circumstances, and until we have found this, or at all events some reasonable approach to it, we cannot with a light heart adopt, as our Continental friends have done, a smokeless powder for the use of our troops. Gunpowder we know all about, it is a good honest mixture, and, sorely tried as it frequently is ashore and afloat, it may be always reckoned on to do its duty so long as we keep it dry. But when we come to high explosives, specially when these are chemical compounds, and from their very nature more or less unstable compounds at that—we, more than any other people, must exercise the utmost precaution in their general adoption, and be sure that neither the damps and heats of India, the salt air in our naval magazines, nor the cold of Canadian winters, will set these treacherous substances fermenting, decomposing or exploding. Hitherto, perhaps, on the whole Professor Abel's powder, Cordite, has shown the best all-round qualities, and bids fair for final selection."

Various Smokeless Powders.

Besides Cordite and smokeless powders, many other kinds are used: "Poudre B." (Vielle Poudre), invented by M. Vielle, is used for the Lebel rifle, and it emits a thin bluish smoke, and gives a comparatively feeble report. "Melanite" is the name given to a high explosive used for loading shells, and very little is known as to its composition or capabilities; originally it was so unreliable that various alterations and improvements were made, and now it is considered to be perfectly safe.

Other powders called "Ballastite," and "Chilworth Special," or "Amide Powder, are used for military purposes; the latter is made up in hermetically-sealed cases, owing to the deliquescent qualities of one of its ingredients, nitrate of ammonia.

Table 4 gives a series of interesting results, comparing together the effects of black gun-powder and brown gunpowder, with "Chilworth Special," in a manner which clearly shows the chief advantages of the new kind of powder.

TABLE 4.

Calibre.	Charge.	Powder.	Projectile.	Muzzle Velocity.	Chamber Pressure.
inches.	lbs.		lbs.	F. S.	tons.
4·725	12	Black Powder	45	1850′	15
	12	C., special	45	2250′	15·5
6	60	Brown Powder	100	2260′	15
	38	C′., special	100	2340′	16·5

Much the same character of results arise from a comparison between Cordite, or any other smokeless powder, with black or brown gunpowder; and the table shows how, in one case, an increase of chamber pressure of half a ton extends the muzzle velocity 400 feet per second. That is, $3\frac{1}{3}$ per cent. extra initial pressure gains 21 per cent. increased velocity.

Or taking the 6-inch gun, a charge of "Chilworth Special," reduced by 22 lbs. as compared with brown powder, gives 1·5 tons extra initial pressure, and 80 feet per second increased velocity.

All these considerations lead to the conclusions pointed out in the first part of this memorandum; namely, that when the gun has been constructed in the strongest manner there remains another problem to be solved.

This problem is the combining of a smokeless powder in such proportions as shall give the highest average pressure, conjoined with such slow burning, as shall not needlessly strain the materials of which the gun is constructed.

Another powder, known commercially under the name "Smokeless Powder," has been manufactured since 1884 for sporting purposes by the Smokeless Powder Company, and more recently they have taken up the manufacture of two kinds for purely military purposes.

One (SR) is intended for the Martini-Henry rifles of ·420 and ·450 inches bore, while the other class, called "Rifleite," is for the magazine rifles of ·303 inches bore, and for quick-firing guns.

There has been sufficient experience of Cordite and this smokeless powder to be sure of their safety and stability in this country, so that both may be considered out of that early experimental stage through which all new inventions must pass. Experience is now being gained with the use of these powders in India and Canada, and before long it will be known whether they are in any way injuriously affected by hotter and colder climatic conditions than prevail in England.

For heavy artillery the rifleite composition, with certain modifications, might be advantageously employed, but the powder must be made to assume a different form.

Its grains must be enlarged in the same manner as gunpowder is treated at present, to lessen the rapidity of explosion, and the magnitude of its cubes must be proportioned to the calibre of the gun.

This conclusion is, however, somewhat of a theoretical kind, as no heavy artillery has yet been supplied with a powder answering this description; and, indeed, it is quite possible that some of the compounds in which picric acid shares a prominent part may turn out the best for heavy guns.

Comparison between the Quantity of Gunpowder or Smokeless Powder for loading Cartridges.

One ton of this smokeless powder serves to load 360,000 Martini-Henry cartridges, and this is rather more than double the number that can be loaded from one ton of ordinary black gunpowder, consequently one million Martini-Henry cartridges, loaded with smokeless powder, weigh about three tons less than the same number loaded with gunpowder; and the saving, even in transport alone, becomes very important.

PART III.

MACHINERY REQUIRED FOR MANUFACTURING MODERN EXPLOSIVES.

Machinery required for the manufacture of smokeless powder resembles, in some respect, that which is in use for the manufacture of gunpowder.

If it be decided to manufacture the class of smokeless powder called Cordite, which, in the author's opinion, is the best of all smokeless powders, then the machinery required to cover the whole of the process should embrace the following :—

1. A chemical plant for the manufacture of those acids and chemicals necessary for the production of guncotton.

2. A complete plant for the manufacture of guncotton, and this plant, while providing the material which forms the basis of Cordite, is also useful for the production of guncotton for various naval and military purposes, such as for charging fixed buoyant or floating mines, charging torpedoes, &c.

3. A plant for the manufacture of Cordite for use in Martini-Henry or Magazine rifles, and for Maxim, Nordenfelt or Gatling guns, and for ordnance generally, up to the largest calibres.

General Arrangements for a Factory.

Although the processes involved in the manufacture of smokeless powders are generally less dangerous than those for gunpowder, yet as some of these require a tolerably uniform temperature, and on no account may be carried out in excessive heat, it is desirable to locate the works in a part of the country where uniform climatic conditions most nearly prevail; also, as the processes should be carried on in a scattered manner, a factory for making any kind of explosive necessarily occupies a considerable area of grounds, so that the processes can be carried on in comparatively small and separated buildings, set at least 40 yards or metres apart. In case any one building should explode, it neither destroys the whole factory, nor causes any serious diminution in the quantity turned out. The buildings should have thick walls, with double roofs, and be protected from the direct rays of sunshine, so that on no account shall they become too hot.

As an additional security to protect the factory from the effects of a lateral explosion, it is usual to surround these buildings, where the more dangerous processes are carried on, with earthen embankments, so that the main force of any explosion shall be expended upwards, causing a comparatively small lateral disturbance, which might otherwise involve the destruction of adjoining buildings by concussion, whenever the contents of one of them meet with disaster.

For similar reasons, the incorporating or kneading mills adjoining the engine-house should be separated from it by a strong wall, and the general machinery should be scattered in detachments over the ground.

Thus it will be seen that a factory of this class should not be erected near a town, although it should be in a situation where adequate military protection can be provided.

Such considerations as these scarcely come within the scope of this memorandum, yet they belong to the subject, and it may further be remarked that powder mills should not be placed too near a navigable river, where they might be bombarded by a hostile fleet, nor too near to the frontier of any foreign power, whose first object after, or perhaps before, a declaration of war, would be to seize the factory, and so paralyze the national defences.

WATER-CARRIAGE AND POWER.

The most desirable situation is a level country, where canals can be used to convey away the explosives when manufactured; or to move them from place to place; and if there were a fall of water, the canals would be at two levels, and it would be cheaper and better to drive the works by turbines, than to find coal for steam-engines.

Powder mills employ water-power largely, and a canal is generally made leading to every separate building where power is required; the canal is raised above the surrounding country, and serves to carry boats for transferring the powder from one place to another.

TEMPERATURES.

Many chemical processes are most successfully carried out within comparatively narrow ranges of temperature, and this is of the utmost consequence in the manufacture of guncotton, nitro-cellulose, or nitro-glycerine, as neglect of this precaution has produced disastrous results.

This being so, it would be necessary to arrange means for warming or cooling the buildings, wherever the climate is subject to considerable variations.

Warming can be accomplished by laying hot-water pipes wherever required, and these could be heated by steam pipes carried underground, or less safely by furnaces placed at a distance from the powder building.

But for cooling purposes nothing can be better designed than engines driven by compressed air, for, on the exhaust being discharged into any room, it at once expands, and serves as an excellent and cooling medium.

LIGHTING THE WORKS.

Oil Lamps.

Oil lamps placed outside windows of the various buildings have long been used for powder mills, and could easily be applied for lighting up the several buildings of a smokeless powder factory, but it is worth consideration, whether this simple arrangement might not be replaced by another system, namely, electric light.

The greatest disadvantage attending the use of electricity, apart from its extra cost, would be the necessity of having specially-trained men to look after the dynamos, whereas any labourer would be able to manage lamps.

Electric Lighting.

Machinery for the production of electricity needs to be of very high class character, and is somewhat liable to the risk of becoming damaged, so that to avoid any stoppage it ought to be provided in duplicate.

If one dynamo or engine should happen to be out of order, then the chances are that the other will be in a position to provide all the light and power required.

Two such engines and two dynamos might be set up in a special department of the buildings containing the main engine; and as there can be no necessity for extraordinary economy in space, the engines and dynamos might advantageously be separate, and so arranged that either engine could drive either dynamo by a belt from a countershaft common to all.

The electric current could be conveyed by wires on ordinary telegraph poles for arc or incandescent lights, for lighting up the whole establishment at night, and a current might even be provided to drive machinery in isolated buildings where power will be required, instead of water-power or compressed air.

In all electric light installations, it is usual to provide a reserve or store of current, in storage batteries, and this is a commendable practice. The main current is transmitted directly from the dynamos to the lights, and any overplus passes into the storage batteries; or, if it should be more convenient, the batteries can be charged during such times as there is no demand for light.

A current can always be taken from these storage batteries, so that even if the engines are standing, any building can be lighted up in a moment by the night watchman. If electric motors should be used for driving isolated machinery, they can be worked from storage batteries without there being anything else going on in the factory.

Electric lighting and transmission of power may thus be combined, and as both systems have now reached a stage of practical success, there is nothing of an experimental character in their application to a powder factory, unless, perhaps, as to their safety in such an application.

Compressed Air-power.

Should there be no water-power available, the next best method for driving machinery in isolated buildings would be compressed air, which is now successfully used for driving tram-cars, and machinery of many kinds, by Rigg's Revolving Engine, which works noiselessly, and is not subject to the ports being choked by ice produced from the expansion of damp compressed air. Compressed to about 8 or 10 atmospheres, it travels in pipes underground, and is about the cleanest and most useful power extant.

Turbines are often used for driving air-compressing pumps, and power so obtained can be transmitted for long distances with cheapness and efficiency.

TRANSMISSION OF POWER.

It frequently happens that water-power can be obtained at some distance from a locality convenient for the erection of a factory, and in such cases the question of its transmission is brought into prominent notice.

There are four systems by which this can be done.

1. Compressed air, carried in pipes.
2. Hydraulic pressure, also carried in pipes.
3. Wire ropes and pulleys.
4. Electricity, conveyed by wires.

(1.)—*Compressed Air* has been employed to a very great extent for mining operations where the water-power obtained through a turbine is used to drive air-compressing machinery. This pressure can be conveyed very long distances through pipes, and at but trifling loss from friction; and if the air can be heated before being used to drive a motor, there is no better system extant for obtaining a higher return in power for the heat expended.

(2.)—*Hydraulic Pressure* is most extensively used for driving isolated machinery, such as cranes or capstans in docks. A pressure, usually of about 700 lbs. per square inch, representing an equivalent head of 1600 feet, is transmitted through cast-iron or steel pipes from the pumping station, to any place where lock gates, or bridges, cranes, or capstans have to be worked. Very little loss of pressure occurs when these pipes are of sufficient capacity, but the engines generally used consume as much water when running empty as when fully loaded.

Such extravagance with steam would never be tolerated by any scientific engineer; but it is only quite recently that hydraulic engines have been provided with a governor which alters the stroke, and so regulates the supply of water according to the demand for power.

(3.)—*Telo-Dynamic Transmission* of power by wire ropes had its origin and most extended application in Germany and Switzerland. Owing to the great tensile strength of steel wire rope, and the high velocity at which it can be driven over large pulleys, very considerable amounts of power are conveyed long distances over hills and valleys, for many years past; but the cost of maintenance is extremely high, and the system seems gradually being displaced by electric transmission.

(4.)—*Electric Transmission.* Dynamos driven by turbines or hydraulic engines are used for transmitting electric currents of high potential to drive other dynamos arranged as motors, at long distances from the source of power.

It is found that practically the same quantity of electricity can be driven through a copper wire of any given sectional area, however high may be its pressure or voltage, so it becomes manifest that the first cost is lessened by using the highest workable pressure.

This consideration has gone so far in many cases as to render contact with the wires fatal to the life of men and horses, so that there is some doubt as to the general advisability of using electricity in the only form through which its economical applicability for long distance transmission is available, and it cannot be used at all in situations where the insulated wires come in contact with water.

Comparisons. For very long distances, hydraulic pressure and telo-dynamic transmission are not so desirable as compressed air or electricity, so that the choice remains with these two.

If electricity be used for lighting purposes, the same staff might attend to dynamos for the transmission of power; but by taking everything into consideration it would appear that compressed air stands before all its rivals. This is not only because of its first cost, but because its maintenance is less expensive.

The economy of transmission is great, though really where ample water-power exists, this seems a minor consideration, while its safety and durability are far beyond that of the delicate and sensitive machinery required for electrical purposes. Moreover, it requires trained electricians to look after dynamos, while any engineer can do all that is required to keep compressed-air machinery in working order.

PART IV.

FACTORY FOR GUNCOTTON, NITROGLYCERINE, AND SMOKELESS POWDERS.

In order to fix the ideas in connection with the manufacture of smokeless powders, it will be well to assume a certain class of powder and minimum production per annum.

Such an establishment may further be assumed, capable of making smokeless rifle powders suitable for Martini-Henry rifles of ·420″ bore, such as the SR of the Smokeless Powder Company, and also making a powder suitable for the new magazine rifle of ·303″ bore, like the rifleite produced by the same company.

The object of any manufacture during the present transition time would be to make a powder that can be used with the existing vast stock of large-bore rifles, as the full benefits expected from the new powders cannot be attained, except with rifles of smaller bore and machine guns, while heavy artillery must wait for reconstruction, and use a powder in the meantime suited to its present capabilities. But a smokeless powder for the existing heavy artillery must be made for the guns in stock, and the great variety existing makes the problem one which cannot be solved without knowing the armament of any particular nation that may be considering the erection of a factory for themselves. The materials required for making a powder for rifles, machine-guns, or heavy guns, are practically the same, differences being less in chemical composition than in the size of grain (or diameter of rod, if "Cordite" be the powder intended).

It will be easy to understand that a powder for pistols, for example, must burn more quickly than one for rifles, and a powder for heavy guns must burn more slowly than a powder for rifles.

If, for example, it be assumed that a factory has to be erected capable of an annual production of about 200 tons (400,000 pounds), half the quantity being for powder suited to the Martini-Henry ·450″ bore, while the other half would be adapted for the new magazine rifle of ·303″ bore, or machine-guns; then as 200 tons of smokeless powder would load about 71 million cartridges, that is, about 200 rounds for an army of 350,000 soldiers, such an army would use the whole 200 tons produced by the factory in one year, leaving nothing in reserve.

The value of 200 tons in England would be about £120,000, calculating the smokeless powder as being worth £600 per ton, besides the cost of carriage; so that by setting up a factory abroad, the cost of building the factory, acquiring the process, and purchasing the machinery, would very soon repay itself.

But, after all, the cost of powder is small in comparison with that of new rifles, which any nation adopting the magazine rifle would have to pay. This cost would vary from £4 to £5 each rifle, or about £1,200,000, to £1,500,000 for 300,000 rifles, whether made in its own arsenal, or purchased from abroad.

In order to manufacture a smokeless powder, a factory of three departments would be required: one for making guncotton, another department for making nitro-glycerine, and a third department devoted to making the "Cordite," or other smokeless powder.

Machinery for making Guncotton.

The materials required for making guncotton are simply cotton, or other form of woody fibre, also concentrated nitric and sulphuric acids, in the proportions one nitric acid to two sulphuric acid; the latter acid taking no further part in the chemical reactions than acting as an absorbent of any free moisture, and such water as may be produced during nitrification of the cellulose.

The cotton has to be thoroughly dried in the first instance, and this is accomplished by vertical steam-jacketted cylinders, through which a current of air is drawn to carry off the watery vapour. This apparatus was designed by the writer for the Guncotton Works at Stowmarket, and it is found so effective that the cotton reaches a condition of such absolute dryness, that its weight increases rapidly by moisture being absorbed from the atmosphere, and it must therefore be kept in closed vessels.

The next operation is to immerse the dried cotton into a bath of nitric and sulphuric acids, and a hood is placed over this earthenware bath, and a steam-jet provided to carry off the acid fumes which arise during the process.

After the cotton has laid a sufficient time in its acid bath, it is most thoroughly washed; and unless this process is effectually done, there is considerable risk of spontaneous decomposition and explosion, on exposure to heat and light.

This effect arises from the decomposition of resinous or fatty substances retained within the cotton fibre, and the spontaneous decomposition leads to the development of nitrogen acids and the risk of explosion. Under Sir Frederick Abel's system for manufacturing guncotton, the cotton is next taken from the acid bath to a pulping machine similar to the arrangement employed by paper-makers, and it is there most thoroughly disintegrated and washed. Its appearance becomes exactly that of paper pulp, and it is treated in a similar manner, being filtered and afterwards compressed in a powerful hydraulic press.

It is compressed into cakes or beads which can be strung together, or into any other form desired.

It is not readily exploded in a wet state, except through the intervention of a pistol and detonator, and ranking as it does with violent explosives, it is remarkably free from danger, and very safe to handle.

Various substitutes have been proposed and used instead of cotton for the manufacture of nitro-cellulose, namely, paper, straw-pulp, wood-pulp, &c. Some of these require from twelve to twenty hours' immersion in the nitro-sulphuric bath to complete their chemical transformation.

They also give slight differences in the resulting explosive produced, and the choice of the kind of cellulose forms one of the usual trade secrets

Appliances for manufacturing Nitro-Glycerine.

Nitro-glycerine is made by mixing glycerine, in small quantities at a time, with concentrated nitric and sulphuric acids, in the manner described on page 43, and so far it corresponds exactly with the manufacture of guncotton.

During the process of nitration, the bath must be kept cool by a coil of piping, through which a current of cold water is flowing; great care and attention is required during the preparation of this dangerous compound, and the temperature must be carefully watched, for if it rises too high, there is more than a risk of an explosion of a most disastrous character.

But little machinery, from an engineering point of view, is required for the manufacture of nitro-glycerine, and only such simple appliances as suffice for the early stages of guncotton, for the process has more connection with chemistry than with engineering.

Water-supply.—As a liberal supply of cold water is needed in a nitro-glycerine factory, pumping machinery must be provided, unless there be a natural head of pressure available.

Compressed Air is found the most convenient agent for mixing the acids and aiding the process of nitrification, and it requires special pumping machinery driven by steam or water-power for its production.

Heating Apparatus.—Then, as temperature plays so important a part in this manufacturing process, it is essential to provide a heating apparatus for maintaining the buildings above the comparatively high freezing point of the explosive oil.

Such simple heating apparatus would consist of a furnace, and boiler fixed at some distance from the nitrating house, and protected from it by earthen embankments.

After this adjunctive machinery has been provided, the actual apparatus required for manufacturing the oil itself is very simple. Each mixing vessel bears considerable resemblance to a still, and one apparatus consists of a vessel made of thick lead, containing several thick coils of the same metal, through which a current of cold water is conveyed for the purpose of keeping down the high temperatures resulting from the addition of glycerine to the mixed acids. Each leaden vessel stands by itself, clear of all surrounding machinery, and in every well-ordered factory it is fixed over a large water tank. The contents can be discharged at once through an earthenware cock, underneath the leaden vessel, should the electric thermometer ever ring too near an approach, 104° Fahrenheit (40° Centigrade or Celsus), the temperature at which spontaneous disintegration of the explosive occurs. Each apparatus is provided with a safety-valve in the cover, also a valve for the admission of glycerine under the control of the operator, and a thermometer, as already mentioned, with electrical connections, by which he can watch the temperature and regulate the flow of glycerine, he being protected behind an earthen embankment.

The impure nitro-glycerine is first separated from the residue of acids by decantation, or by a syphon, and conveyed through pipes by water-carriage to another building, where it is thoroughly washed until no acid effect is shown on blue litmus paper; any unperceived residue of acid being finally neutralized in a bath of carbonate of soda in which it is agitated by compressed air.

All acid fumes are carried away by a hood and ventilating shaft of earthenware, into which a steam jet is applied for the double purpose of providing a certain amount of friction, and for dissolving a portion of the acids.

Special Machinery for Smokeless Powders.

The machinery required for making any kind of smokeless powder is practically the same, and the processes of mixing and thoroughly incorporating under "stones" like mortar mills, followed by sifting and granulating, are common to all.

Some smokeless powders are made into sheets, through rollers, and cut into small squares, while others, of which "Cordite" forms the chief representative, are squirted through holes under the influence of hydraulic pressure while in the form of a pasty mass.

This continuous cord is received on reels and dried by steam, so as to evaporate the solvent. It then hardens, and is cut up into suitable lengths for use, and the diameter of the "Cordite" determines its rate of combustion and explosiveness.

Instead of filling cartridges with a powder as usual, a number of cordite-rods are collected together in a special machine, whereby they are pushed into a cartridge-case, and cut off to the proper length. The bullet is afterwards fixed in the usual manner.

Thus the difference between smokeless powder and " Cordite " for rifles or for heavy artillery is not so much in their composition as in their mechanical condition, in size of grains for the one, or in the thickness of rods for the other sort.

The object of these differences is to cause the powder to burn more slowly, giving more time for the shot to travel, thus reducing the strain upon the gun.

The same factory, therefore, that would serve for making " Cordite " or any other class of smokeless powder, would provide the right material for rifles, magazine rifles, or heavy guns.

Conclusion.

From the foregoing pages it will be seen that not only the production of new classes of powder for propelling shot and for bursting shells are in somewhat of an experimental stage at the present date (1892), but that the influence of the changes now going on profoundly modify the conditions determining design and construction of heavy guns and rifled small-arms.

The great problem to the solution of which all military authorities are chiefly directing their attention at the present time, is to produce a powder for guns which shall serve a double purpose: namely, that of forming a suitable explosive for the *existing* stock of guns and rifles, and which shall at the same time give higher results in rifled artillery specially designed to suit its peculiarities.

All artillerists are working towards this end, and some affect great mystery as to what they are doing; although their "secrets" are not always worth the trouble of finding out.

A good deal of unproved theory has been put forward from time to time in connection with guns and explosives; and it would be unwise to conclude that any finality has been reached up to the present time. But there seems no doubt that eventually a complete reorganization of artillery must be made in order to gain the fullest benefit of smokeless powders, and there is some uncertainty as to the complete lines on which such reorganization must proceed.

There is, however, no doubt that some, if not the major portions, of the benefits derivable from smokeless powders can be had by very little changes in guns as made at present.

The practical conclusion of the whole matter seems to lead to a gradual modification of new artillery in the direction inculcated in the preceding portion of this memorandum: in the meantime, making the powder so as to suit existing guns, and slightly varying the details of its manufacture from time to time, as new guns supersede the old ones.

By this moderate progressive system the greatest efficiency becomes possible with the fewest changes in existing armaments, and it only becomes necessary to add supplements from time to time, that all existing text-books may be brought up to date.

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