Researches on Explosives. Part III

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VI. *Researches on Explosives.—Part III.*

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[PLATES 1–13.]

THE Researches which I venture to communicate to the Royal Society are, for the new explosives cordite, modified cordite, and nitro-cellulose, a continuation of the same modes of research, adopted in the experiments I made many years ago upon fired gunpowder with regard to the pressure and other phenomena attending its decomposition, and which appeared in the 'Philosophical Transactions.'* In the present investigations the same general methods have been followed, but with apparatus greatly improved and of much greater delicacy.

The Academy of Sciences of France did Sir F. ABEL and myself the great honour to appoint MM. le Général MORIN and BERTHELOT to report on our paper, and after giving an extended analysis of the results of our experiments the reporters concluded † : " Par cette analyse trop succincte de l'important travail que MM. NOBLE et ABEL ont soumis au jugement de l'Académie, on peut voir que malgré certaines critiques auxquelles nul travail humain ne saurait échapper, l'ensemble de leurs recherches n'en constitue pas moins une œuvre capitale, propre à jeter un grand jour sur toutes les questions qui se rattachent aux effets des poudres."

A paper by M. BERTHELOT in the same No. of the 'Comptes Rendus' draws attention to the chief point upon which that eminent chemist differed from ourselves.

A study of the variations in the products when the decomposition of gunpowder was conducted under pressures widely different, varying in fact between 1 ton per sq. inch and 35 to 40 tons per sq. inch, led my lamented friend Sir F. ABEL and myself to state that, according to our view, "any attempt to express even in a complicated chemical equation the nature of the metamorphosis which a gunpowder of average composition may be considered to undergo, would only be calculated to convey an erroneous impression as to the simplicity or definite nature of the chemical results, and their uniformity under different conditions, while possessing no important bearing upon an elucidation of the theory of the explosion of gunpowder."

* NOBLE and ABEL, 'Fired Gunpowder,' Part I., 1875.
† 'Comptes Rendus,' vol. 82, p. 492.

M. BERTHELOT, in the memoir to which I have referred, considers that the view which we took was contrary to all that was known in chemistry.

It is no light thing to differ from so great an authority as M. BERTHELOT; but the innumerable experiments I have since made with various modern explosives, in which the decomposition is of a simpler nature than that of fired gunpowder, have only confirmed me in the opinion that Sir F. ABEL and I then expressed.

Thus in a paper published in the 'Proceedings of the Royal Society,'* I pointed out that when gun-cotton was fired under a great variation of pressure, the variations in the proportions of the resulting gases were both great and regular. In passing, for instance, from explosions under a pressure varying from 1·5 ton per sq. inch (228·7 atmospheres) to 50 tons per sq. inch (7621·7 atmospheres) the volume of carbonic anhydride increased from 26·49 per cent. to 36·18 per cent., while the carbon monoxide decreased from 36·66 per cent. to 27·57 per cent.

There were also other differences, though not quite so marked, such as the steady decrease of free hydrogen and the large and steady increase of marsh gas.

In the researches on gun-cotton to which I have alluded, certain data, such as the units of heat and the quantity of water formed by the explosion, although determined, were not determined under the varying conditions with regard to pressure and the quantity and nature of the gases generated, under which the explosion took place.

In the researches I am about to refer to, all the data connected with the explosion have been carefully determined, and I preface an account of the experiments themselves by a description of the varied apparatus adopted, or specially designed, for determining the tension of the gases generated by the explosion, the volume of the permanent gases and their nature, the quantity of water formed, the units of heat generated, the time taken to complete the explosion under different pressures and different dimensions of the cords, tubes, or ribbons, these being the forms under which the explosives are generally made up.

I have made experiments also to determine the time in which the exploded gases part with their heat to the walls of the vessel in which they are confined.

These investigations have opened out many suggestive points, but in the present paper I propose to confine myself to a description of the apparatus used and the results obtained, giving also a *résumé* of the calculations made to test the accuracy of the observations.

Commencing with the apparatus for firing the explosives experimented with at different densities, obtaining the gases for analysis, and measuring their total volume, the vessel A, in Plate 1, is one of the explosion cylinders used for these experiments; B is the plug closing the vessel, on which also is shown the arrangement by which, when desired, the gas is allowed to pass at a small pressure through the tubes, either

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* 'Roy. Soc. Proc.,' vol. 56, p. 209.

to the gasometer C or at pleasure into the gas tubes D, which, before the experiment, are filled with mercury, the stop-cocks above and below being closed; E is a thermometer for determining the temperature of the gas when its volume is measured.

Immediately after the explosion, if the vessel be quite tight, the valve at B is very slightly opened and the gas allowed to pass slowly through the tube F, containing pumice-stone and concentrated sulphuric acid, into the gasometer.

When it is quite certain that all air is removed from the conducting tubes, the gas is allowed to flow into one of the gas tubes D, and shortly afterwards or at fixed intervals of time into the other two tubes, the quantity of gas in the tubes being added to that measured in the gasometer, the height of the barometer and the temperature of the gas at the moment of measurement being also determined.

When the whole of the gas has been transferred to the gasometer, and the temperature and barometric pressure taken, the cylinder is opened. A considerable quantity of water is always found; as much as possible of this water is collected by means of a weighed sponge placed in a weighed vessel, and closed by a ground glass plate. The amount of the water so collected is determined by weighing in the usual manner.

After all the water that it is possible to remove with the sponge is collected, a weighed vessel of calcium chloride is placed in the cylinder, which is then closed, and left for one or two days, when the same procedure is followed with a second calcium chloride vessel, after which the cylinder is generally found to be perfectly dry.

The next point to be determined is the amount of heat generated by the explosion.

For this purpose a strong steel vessel, the section of which is shown in Plate 2, and of which the heat capacity is carefully determined, is employed. The calorimeter used is practically of the same construction as that described by OSTWALD in his 'Manual of Physico-Chemical Measurements.'

A section of this calorimeter is also shown in Plate 2, the corresponding inner and outer surfaces of the several vessels being nickel plated. For some hours before the experiment the calorimeter is kept in a room maintained at as even a temperature as possible, the explosion vessel itself with the charge to be exploded being kept in the water as shown, so that the whole system may assume practically the same temperature.

The rise of temperature due to the explosion being approximately known from previous experiments, the water in the outer cylinder before firing is kept at a temperature about half way between the initial and final temperatures of the inner vessel.

The thermometers employed for these determinations are calorimetric, specially made for calorimetric experiments, and are only used for observing changes of temperature, and not for determining absolute values. The range of measurement in the thermometers I used was about 8° C., but by a special contrivance these 8°

can be brought to any point of the thermometric scale that may be desired. The temperature can be read approximately to 0·001° C.

Full illustrations of a few of the calorimetric observations will be given with the corresponding calculations, and a *résumé* of the results of the experiments at the end of the paper.

The analysis of the gaseous products of explosion was carried out by means of SODEAU'S gas analysis apparatus,* the principal features of which are shown in Plate 3.

Mr. SODEAU'S apparatus is admitted to be the most convenient that has been yet devised. I am indebted to him for the description of his apparatus and the mode of analysis followed.

The tubes used for measuring and correcting for variations of temperature and pressure are placed in a cylindrical water-jacket. The measuring tube M is of 50 cub. centims. capacity, and is graduated in $\frac{1}{10}$-cub. centim. divisions. Its upper end terminates in a capillary three-way stop-cock N, arranged so that the capillary K may be placed in communication either with the interior of the measuring tube or with the bent tube U containing water. The zero point of the graduation is at the outer side of the plug of the stop-cock N. The level tube L communicates with the measuring tube by means of a side branch, bent so as to prevent any entangled air bubbles from reaching the measuring tube. The lower end of the level tube is connected to a T piece, one end of which is provided with a stop-cock and leads to the mercury reservoir, whilst the other is prolonged across the table to a point near the reading telescope, where it terminates in a piece of thick-walled rubber tubing, the compression of which by a broad screw clip affords a means of accurately adjusting the level of the mercury without taking one's eye from the reading telescope.

In order to render the apparatus more compact, the reading telescope is placed on the gas analysis table instead of on a separate support, and all graduations are consequently on the side opposite to that from which the stop-cocks are manipulated. An illuminating arrangement slides on the rod P.

The corrections for variations of temperature and pressure are found by means of the "Kew Principle" correction tube C, which is so called because, as in the "Kew" barometer, the disturbance of the level of the liquid is allowed for in the graduation of the instrument, instead of being adjusted before each reading is taken. It consists of a cylindrical bulb having a stop-cock at its upper end, and attached below to a U tube, which is graduated on one limb and filled with water up to the zero mark whilst the stop-cock is open. The volume of air contained in the bulb is such that the water is displaced to the extent of one small division by a change of temperature and atmospheric pressure, which will cause a gas to experience an alteration of volume amounting to 0·1 per cent. These small divisions are further

* 'Journal of the Society of Chemical Industry,' Feb. 28, 1903, page 187.

subdivided into tenths by eye estimation. Errors of parallax are avoided by the use of a mounted lens sliding on the rod R, and the corrections are thus read directly in percentages as easily as the temperatures would be read by means of a thermometer.

Absorptions are carried out in separate pipettes, one of which is shown in position. About 20 cub. centims. of the absorbent is usually confined over mercury in the bulb E, which is slightly inclined in order to facilitate the return of the unabsorbed gas. The horizontal bulb D receives the mercury displaced by the gas. The bulb F contains clean mercury, and, like the bulb E, can be placed in communication with the capillary G by means of the three-way stop-cock H.

The explosion pipette resembles that of DITTMAR, but has a three-way stop-cock and mercury bulb arranged as in the absorption pipettes.

In conducting an analysis, the sample tube is connected to the measuring tube by means of a capillary tube previously filled with mercury, and the gas drawn in by lowering the reservoir. After the mercury has been roughly levelled, the stop-cock N is turned so as to connect the capillary K with the tube U, and an absorption pipette, containing caustic potash solution, connected to the measuring tube by means of thick-walled rubber tubing, the ends of the capillaries being made to meet. A little water is then sucked through the capillaries into the bulb F, and mercury allowed to run back and fill the capillaries. The stop-cock leading to the large mercury reservoir having been closed, and the level tube being open to the atmosphere, the mercury is accurately levelled, as already described, and the volume of the gas read by means of the reading telescope. A reading of the correction tube is also taken.

In order to determine the amount of carbon dioxide present, the gas is driven over into the absorption pipette, followed by sufficient mercury to clear the capillaries, and the pipette well shaken in order to make the absorption complete. A little more mercury is then run over in order to clear away the potash from the bottom of the capillary attached to the absorption bulb, and the stop-cock N reversed so that the mercury in the capillaries runs into the tube U. The stop-cock N is then again turned and the gas slowly passes into the measuring tube, the rate being controlled by the stop-cock H, which is reversed as soon as the absorbent reaches it, so that the gas may be swept out of the capillaries by means of clean mercury from the bulb F. The stop-cock N is closed as soon as it is reached by the mercury. The gas is again carefully measured and the decrease of volume (after the correction for alteration of temperature and pressure has been applied) is equal to the amount of carbon dioxide originally present. The residue is then treated with alkaline pyrogallol, in order to ascertain whether any trace of air has been left in the connecting tubes during the collection of the sample and has so contaminated the gas. (This is more likely to occur when the explosion has taken place under feeble pressures and but little gas been produced.) If any oxygen is absorbed by the pyrogallol, its volume is multiplied by 4·8 and the product (representing the volume of air present) deducted from the

volume of gas taken for analysis, in order to obtain the volume of uncontaminated gas in the sample, and hence the correct percentages of the various constituents.

Carbon monoxide is next removed by prolonged treatment with two successive portions of acid cuprous chloride solution. After absorption in the first cuprous chloride pipette the gas is directly transferred to a second pipette containing a solution which has not previously absorbed more than a trace of carbon monoxide, this transference being accomplished in practically the same manner as the return of the gas to the measuring tube, which takes place after transference to a pipette containing a little water, which removes the traces of hydrochloric acid derived from the cuprous chloride solution. An excess of oxygen* is then added, and, after measuring, the mixture is transferred to the explosion pipette, where it is exploded by means of an electric spark after expanding to such a volume as to prevent any marked oxidation of the nitrogen, whilst ensuring the complete combustion of the methane and hydrogen. The residue is next measured in order to ascertain the reduction of volume resulting from the explosion, and the carbon dioxide, produced by the combustion of the methane, is determined by absorption with potash. The volume of the carbon dioxide produced is equal to that of the methane originally present. The contraction due to the combustion of the methane, or in other words, twice the volume of the carbon dioxide, is deducted from the total contraction resulting from the explosion, and two-thirds of the corrected contraction so obtained is equal to the volume of hydrogen.

Finally, the excess of oxygen remaining after explosion is determined by means of alkaline pyrogallol as a check upon the amounts of hydrogen and methane calculated as above. The nitrogen is estimated by difference.

The above represents the routine determination of carbon dioxide, carbon monoxide, hydrogen, methane and nitrogen, as usually carried out, but additional tests have also been employed in order to ascertain whether certain other bodies were present in measurable quantities, but with negative results. Thus some of the gas samples were examined for unsaturated hydro-carbons (ethylene, &c.) immediately after the removal of the carbon dioxide, by shaking the gas with fuming sulphuric acid,† and removing acid fumes in the potash pipette before again measuring. No change of volume was ordinarily observed, and in no case did the change exceed 0·1 per cent., hence the samples did not contain any appreciable quantity of unsaturated hydrocarbons.

The ordinary determinations of contraction resulting from explosion, carbon dioxide

* The oxygen is prepared by the electrolysis of dilute sulphuric acid in a Hofmann voltameter and freed from traces of hydrogen by treatment in a Winkler combustion pipette. A supply is stored over mercury in one of the ordinary absorption pipettes ready for use.

† Fuming sulphuric acid was used in one of the ordinary absorption pipettes, provided with a guard tube containing sulphuric acid, in order to prevent moisture from gaining access to the upper bulb D. Of course no mercury was employed in the absorption bulb, and that in the capillaries was driven into the bulb F when sending the gas into the pipette.

produced, and oxygen consumed, do not afford a means of distinguishing methane from its homologues in presence of an excess of hydrogen; thus ethane, together with its own volume of hydrogen, would give the same numerical results as two volumes of methane. A process of fractional combustion was therefore applied to some of the samples obtained from high density charges, as these contained large proportions of saturated hydrocarbons. After removing carbon dioxide, carbon monoxide and unsaturated hydrocarbons, an excess of oxygen was added and the hydrogen was removed by repeatedly passing over gently heated palladinized asbestos contained in a capillary tube attached to a pipette containing water, as in the ordinary Orsat-Lunge apparatus, until no further decrease of volume occurred. The residual mixture was then examined by explosion, &c., in the usual manner. In each case the volume of carbon dioxide produced almost exactly half that of the decrease, resulting from the explosion, which latter was equal to the volume of oxygen consumed. These ratios agree with those required by the equation

$$CH_4 + 2O_2 = CO_2 + 2H_2O,$$
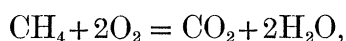
but differ markedly from those which would result with the homologues of methane, thus even with ethane the proportions are 4 : 5 : 7 instead of 1 : 2 : 2. It therefore follows that the saturated hydrocarbons should be calculated as methane, none of the other members of the series being present in appreciable quantities. Examination of the water condensed in the closed vessel showed that the gas could not contain either ammonia or cyanogen in marked quantities, as the distribution under high pressure would so greatly favour the water. The presence of oxides of nitrogen is, of course, incompatible with that of a large proportion of hydrogen, as the gases have slowly cooled from a very high temperature. A trace of sulphuretted hydrogen, sufficient to markedly discolour mercury, exists in the gas when black powder is used as a lighter, but for all practical purposes the gaseous products of explosion may be regarded as consisting entirely of carbon dioxide, carbon monoxide, hydrogen, methane and nitrogen.

One other arrangement of apparatus remains to be described, and that apparatus is used both for determining the time that explosives of various forms and natures require for their transformation, and for determining the rate at which they communicate the heat accompanying the explosion to the walls of the vessel in which the explosion takes place.

The apparatus (see Plate 4) consists of an explosion vessel of the usual form, the explosion vessel being closed at its two ends by gas-tight plugs, through one of which pass the firing wires, while to the plug at the other end is fitted a pressure indicator.

The pressure indicator is provided with a steel plunger of small area, which is exposed to the gas pressure.

An enlarged continuation of this plunger engages the end of a spiral spring a, the

resistance of which has been carefully determined. Attached to this plunger at b is a lever, the fulcrum of which, c, is fixed to the stationary bracket of the indicator, so that, when the spring is compressed, motion is given to the ends of the lever.

Fixed to the lever are two electric magnets d, the one to record seconds, the other to perfect the firing circuit. A rocking bar e is coupled up over the seconds magnet, which is again coupled at the other end by a link f, thus conveying the seconds beats of the chronometer to the pen tracing its path on the revolving drum.

The revolving drum itself is of light wood; fixed to the frame are two rods gg, upon which slides the carriage for carrying the recording pen. The pen is held up by a detent, which is liberated by the firing current passing through the electro-magnet to which the detent is attached. There are two speeds given to the drum, the first a high speed (about 40 inches per second), the second very slow, about one inch per second. The drum is revolved by means of cord bands, which lead from the speed gear of the motor.

Before firing, the fast-speed cord is made to drive the drum, the slow-speed cord running free; about one or two seconds after the explosion the change speed lever is raised, thereby releasing the fast cord and tightening the slow cord. The fast speed is obtained approximately by watching the tachometer, but the actual speed is determined by measuring the length of the second on the recording diagram. The diagram is traced on a sheet of tin foil backed by paper. This is placed on the drum as shown on Plate 4, the edges being joined with gum, the surface being smoked black by camphor.

The chronometer is of the ordinary marine type, but is furnished with a seconds make-and-break arrangement; this being coupled up through a relay to the pressure lever, causes the recording pen to beat seconds till the desired curve is complete.

The action of the apparatus during an experiment is as follows :—

All connections being made, the chronometer is coupled up, the pen carriage beating seconds, but no mark is yet made on the recording tin foil, the pen being held by the detent. The drum is started, and when it has reached the desired speed, as shown by the tachometer, the button of the firing battery is pressed and the circuit is completed at the beat of the next second.

The current simultaneously releases the pen and fires the charge. As quickly as possible the speed is reduced by raising the speed lever and at the same time reducing the speed of the motor. The chronometer continues to beat seconds, thereby giving the relation between time and pressure until the experiment is concluded. The diagram is then removed from the drum by cutting through the point where the pen dropped, this being the beat of the second firing the charge. The sheet is then laid on a tray face up, flooded with thin varnish, and hung up to dry.

For the purposes of these reseaches, which are specially directed to ascertain the differences in the phenomena attending the transformation of explosives fired under different pressures, I have employed three explosives, viz., the cordite known as

Mark I (for which the country has been indebted to the labours of Sir F. ABEL and Sir J. DEWAR), the modified cordite known as M.D., and a tubular nitrocellulose known as R. R. Rottweil.

The general results, which I need not say have necessitated much calculation, are given in tables, but I think it necessary to give the results of a few experiments worked out in full, these being a fair sample of the whole series. In each case I give the reconciliation between the elements determined in the explosive and the same elements found in the gases after explosion.

Taking into account the fact that the explosives themselves are not always of precisely the same composition, and also the nature of the experiments, the reconciliation to which I have referred is a very great deal closer than I expected.

It has been suggested to me more than once that the mixture of the gases might not be homogeneous, that is, that tubes taken at different times from the explosion vessel might not give the same analysis. I have not found this to be the case. Thus, in an experiment where a charge of Rottweil R. R. was fired under a pressure of 20·5 tons per sq. inch (3125 atmospheres), and a tube of the resultant gases was taken so soon as it was certain that all the air contained in the conducting tubes, &c., was displaced, a second tube being taken 6 or 7 minutes later, the analysis gave for the two tubes of permanent gases the following percentages :—

	1st tube.	2nd tube.
CO_2 . . .	28·06 percentage volumes.	28·02 percentage volumes.
CO . . .	34·02 ,, ,,	33·92 ,, ,,
H . . .	17·16 ,, ,,	17·00 ,, ,,
CH_4 . . .	7·41 ,, ,,	7·40 ,, ,,
N . . .	13·35 ,, ,,	13·66 ,, ,,

Taking now the data given by the explosion of a charge of 32·68 grammes of M.D., which was fired at a density of 0·1 under a pressure of 6·9 tons per sq. inch (1051·8 atmospheres), the resultant quantity of gas was

27,486 cub. centims. at 16°·6 C., and under bar. pressure of 751·33 millims.
    = 25,916 cub. centims. at 0° C. and 751·33 millims.
    = 25,621 cub. centims. at 0° C. and 760 millims.

The quantity of water collected was 4·136 grammes, equivalent to 5145·1 cub. centims. aqueous vapour at 0° C. and 760 millims.

The percentage results of the analysis of the permanent gases in volumes are given in Column I., the total volumes in Column II., the percentage volumes, including aqueous vapour, are shown in Column III., and the percentage weights of the total gases in Column IV.

	I.	II.	III.	IV.
	Percentage volumes, permanent gases.	Total, permanent gases, cub. centims.	Percentage volumes, total gases.	Percentage weights, total gases.
CO_2	20·10	5,149·8	16·74	30·82
CO	40·70	10,427·7	33·90	39·71
H	23·10	5,918·4	19·24	1·61
CH_4 . . .	1·00	256·3	0·83	0·55
N	15·10	3,868·8	12·57	14·74
H_2O . . .	—	—	16·72	12·57

The reconciliation between the amounts of C, O, H and N, contained originally in the explosive, and found in the products of explosion, were obtained as follows :—

		C_2.	O_2.	H_2.	N_2.
CO_2* . .	0·2010	0·1005	0·2010	—	—
CO . . .	0·4070	0·2035	0·2035	—	—
H . . .	0·2310	—	—	0·2310	—
CH_4* . .	0·0100	0·0050	—	0·0200	—
N . . .	0·1510	—	—	—	0·1510
Totals		0·3090	0·4045	0·2510	0·1510

Multiplying the carbon, oxygen, and nitrogen by 12, 16, and 14 respectively, we obtain :—

C_2.	O_2.	H_2.	N_2.
grammes.	grammes.	grammes.	grammes.
3·708	6·472	0·2510	2·114

And again multiplying by $2 \cdot 295 = \dfrac{25{,}621 \cdot 0}{11{,}160 \cdot 7}$ we have

	C_2.	O_2.	H_2.	N_2.
	grammes.	grammes.	grammes.	grammes.
	8·510	14·85	0·57	4·850
Add the H_2O	—	3·67	0·46	—
	8·51	18·53	1·03	4·85
In M.D. cordite	9·11	18·66	1·030	4·49†
Difference	− 0·60	− 0·13	0·00	+0·36

In this experiment the quantity of gas and water measured shows that 1 gramme of M.D. under the pressure named above gave rise to 788·4 cub. centims. of permanent gases, or to 946·4 cub. centims. including aqueous vapour.

* Using HOFMANN's notation : $\boxed{\dfrac{\boxed{O}}{\boxed{O}}}\Big\} + \boxed{C} = \boxed{CO_2}$: $\boxed{\dfrac{\boxed{H}\ \boxed{H}}{\boxed{H}\ \boxed{H}}}\Big\} + \boxed{C} = \boxed{CH_4}$.
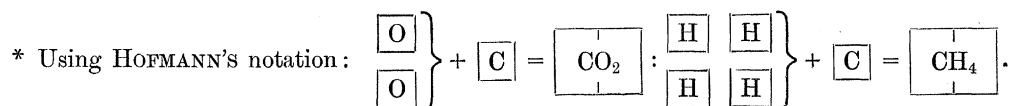
† Including N in cylinder.

Again, with a charge of 99·65 grammes of M.D. cordite and a density of 0·3, the gaseous pressure being 27·62 tons per sq. inch (4210·3 atmospheres), the quantity of gas measured, after being reduced to 0° C. and 760 millims. pressure, was 72,768 cub. centims., while the quantity of water collected was 11·162 grammes, equals 13,885·5 cub. centims. aqueous vapour at 0° C. and 760 millims. pressure.

	I.	II.	III.	IV.
	Percentage volumes, permanent gases.	Total, permanent gases, cub. centims.	Percentage volumes, total gases.	Percentage weights, total gases.
CO_2 . . .	29·40	21,393·7	24·69	42·07
CO . . .	31·10	22,630·9	26·12	28·32
H	17·75	12,916·4	14·91	1·16
CH_4 . . .	6·55	4,766·3	5·50	3·41
N	15·20	11,060·7	12·76	13·91
H_2O . . .	—	—	16·02	11·13

From the above data it appears that the explosion gave rise to 735 cub. centims. of permanent gas and 875·3 cub. centims. total gas when reduced to 0° C. and 760 millims. pressure.

RECONCILIATION.

		C_2.	O_2.	H_2.	N_2.
CO_2 . . .	0·294	0·147	0·294	—	—
CO . . .	0·311	0·1555	0·1555	—	—
H . . .	0·1775	—	—	0·1775	—
CH_4 . . .	0·0655	0·03275	—	0·1310	—
N . . .	0·152	—	—	—	0·152
	1·000	0·3352	0·4495	0·3085	0·152
		× 12	× 16	—	× 14
		= 4·022	7·192	0·3085	2·128

Multiplying again by $\dfrac{72,768\cdot0}{11,160\cdot7} = 6\cdot520$, we have as the weights found in grammes:—

	C_2.	O_2.	H_2.	N_2.
	26·22	46·89	2·01	13·88
Adding for H_2O	—	9·92	1·24	—
Totals	26·22	56·81	3·25	13·88
In cordite before explosion	27·05	56·26	3·33	13·36
Difference	− 0·83	+ 0·55	− 0·08	+ 0·52

Again ,taking from Experiment 1416 an example of transformation at a high pressure, a charge of 81 grammes (including lighter) of Mark I cordite fired under a pressure of 22·5 tons per sq. inch (3429·8 atmospheres), the quantity of gas generated after being reduced to 0° C. and 760 millims. pressure was 54,961·5 cub. centims. As before, the percentage in volumes of the permanent gases is shown in Column I., of the total gas in Column III., and the respective weights of the total gases in Column IV.

The quantity of H_2O collected was 11·96 grammes = 14,878·2 cub. centims. aqueous vapour at 0° C. and 760 millims.

	I.	II.	III.	IV.
	Percentage volumes, permanent gases.	Total, permanent gases. cub. centims.	Percentage volumes, total gases.	Percentage weights, total gases.
CO_2 . . .	31·30	17,203·0	24·63	41·95
CO . . .	29·50	16,213·7	23·22	25·15
H	18·50	10,167·8	14·56	1·13
CH_4 . . .	1·95	1,071·7	1·53	0·95
N	18·75	10,305·3	14·76	16·02
H_2O . . .	—	—	·21·30	14·80

These data give the quantity of permanent gases generated at 686·4 cub. centims. and the total gases at 869·7 cub. centims. per gramme.

Proceeding to compare as before the elements in the cordite and in the exploded gases, we have :—

		C_2.	O_2.	H_2.	N_2.
CO_2 . . .	0·3130	0·1565	0·3130	—	—
CO . . .	0·2950	0·1475	0·1475	—	—
H	0·1850	—	—	0·1850	—
CH_4 . . .	0·0195	0·0098	—	0·0390	—
N	0·1875	—	—	—	0·1875
		0·3138	0·4605	0·224	0·1875
		× 12	× 16	—	× 14
		= 3·766	7·368	0·224	2·625

Multiplying again by $\dfrac{54,961 \cdot 5}{11,160 \cdot 7} = 4 \cdot 9246$, we have for weights in grammes :—

	C_2.	O_2.	H_2.	N_2.
	18·55	36·28	1·10	12·93
Add for H_2O	—	10·63	1·33	—
Totals	18·55	46·91	2·43	12·93
The cordite	18·47	46·94	2·43	12·46
Difference	+0·08	−0·03	0·00	+0·47

Experiment 1401.—At a density of 0·4 a charge of 128·5 grammes of Rottweil nitrocellulose R.R., giving a pressure of 34·9 tons per sq. inch (5320·0 atmospheres), generated 88,689 cub. centims. at 0° C. and 760 millims. pressure, also 15·23 grammes of water = 18,946·1 cub. centim. of aqueous vapour at 0° C. and 760 millims.

GAS ANALYSIS.

	I.	II.	III.	IV.
	Percentage volumes, permanent gases.	Total, permanent gases, cub. centims.	Percentage volumes, total gases.	Percentage weights, total gases.
CO_2	33·70	29,888·2	27·44	45·80
CO	28·90	25,631·1	23·53	24·99
H	14·20	12,593·8	11·56	0·88
CH_4	9·85	8,735·9	8·02	4·87
N	13·35	11,840·0	10·87	11·57
H_2O	—	—	18·58	11·89

Hence we have 690·1 cub. centims. of permanent gases, or 846·8 cub. centims. including aqueous vapour per gramme of explosive. Proceeding to reconcile the elements, we have :—

		C_2.	O_2.	H_2.	N_2.
CO_2 . . .	0·3370	0·1680	0·3370	—	—
CO . . .	0·2890	0·1450	0·1340	—	—
H . . .	0·1420	—	—	0·1420	—
CH_4 . . .	0·0985	0·0495	—	0·1970	—
N . . .	0·1335	—	—	—	0·1335
	1·0000	0·3625	0·4810	0·3390	0·1335
		×12	×16	—	×14
		=4·350	7·700	0·339	1·870

Multiplying again by $\dfrac{88,689 \cdot 0}{11,160 \cdot 7} = 7 \cdot 947$, we have the weights :—

	C_2. grammes.	O_2. grammes.	H_2. grammes.	N_2. grammes.
	34·57	61·08	2·69	14·83
Add H_2O	—	13·54	1·69	—
Totals	34·57	74·62	4·38	14·83
In the R.R. nitrocellulose	35·85	73·33	4·06	15·16
Difference	− 1·28	+ 1·29	+ 0·32	− 0·33

In the reduction of the experiments hitherto considered, it has not been necessary to make any correction to the quantity of gas, as the weight of the gases sufficiently accurately represents the weight of the explosive experimented on, but it occasionally happens, especially at high pressures, that, at the moment of firing, a puff of gas escapes, the leak, however, being generally only momentary, the explosion vessel becoming later perfectly tight. In these cases of course the weight would be in defect, but in a few cases the weight of the gases was in excess, and I proceed to show how these experiments were dealt with.

Experiment 1417.—At a density of 0·45 a charge of 143·91 grammes of M.D. cordite, giving a pressure of 43·22 tons per square inch (6588·2 atmospheres), generated 98,231·9 cub. centims. at 0° C. and 760 millims. pressure; the water collected was 15·59 grammes = 19,384·0 cub. centims. The analysis of the permanent gases in volumes gave :—

	I.	II.		III.	IV.
	Percentage volumes, permanent gases.	Total, permanent gases.		Percentage volumes, total gases.	Percentage weights, total gases.
		cub. centims.	grammes.		
CO_2	36·6	35,952·9	= 70·86	30·56	48·75
CO	24·8	24,361·5	= 30·55	20·71	21·02
H	11·9	11,689·6	= 1·05	9·94	0·72
CH_4	10·7	10,510·8	= 7·54	8·94	5·19
N	16·0	15,717·1	= 19·76	13·36	13·59
H_2O	—	—		16·49	10·73

Now if to the weights given in Column III. we add the weights of water, it will be found that the total weight is 1·44 grammes greater than the charge actually employed. The volume of the gases has therefore been reduced to 97,589·5 cub. centims., thus giving 676·3 cub. centims. of permanent gases or 810·6 cub. centims. total gas for each gramme exploded.

RECONCILIATION.

		$C_2.$	$O_2.$	$H_2.$	$N_2.$
CO_2 . . .	0·366	0·183	0·366	—	—
CO . . .	0·248	0·124	0·124	—	—
H . . .	0·119	—	—	0·119	—
CH_4 . .	0·107	0·054	—	0·214	—
N . . .	0·160	—	—	—	0·160
	1·000	0·361	0·490	0·333	0·160
		×12	×16	—	×14
		=4·332	7·840	0·333	2·240

Multiplying again by $\dfrac{97,589\cdot5}{11,160\cdot7} = 8\cdot744$:—

	$C_2.$ grammes.	$O_2.$ grammes.	$H_2.$ grammes.	$N_2.$ grammes.
	37·88	68·56	2·91	19·59
Add H_2O	—	13·86	1·73	—
Totals	37·88	82·42	4·64	19·59
In M.D.	39·06	81·24	4·80	19·29
Difference	−1·18	+1·18	−0·16	+0·30

Experiment 1496.—At a density of 0·5 a charge of 155·84 grammes of cordite were fired under a pressure of 52·84 tons per sq. inch (8054·7 atmospheres). On firing, a slight escape of gas passed the firing plug, which, however, became immediately tight. The quantity of gas measured was 93,199·8 cub. centims., when reduced to 0° C. and 760 millims. pressure. 21·135 grammes of water were collected, representing 26,291 cub. centims. aqueous vapour. At the standard temperature and pressure, the gas analysis was as follows :—

	I. Percentage volumes, permanent gases.	II. Total, permanent gases.		Total, grammes.
		cub. centims.	grammes.	
CO_2 . . .	41·95	39,097·3 =	77·06	
CO . . .	19·10	17,801·2 =	22·32	
H . . .	12·05	11,230·6 =	1·01	149·49
CH_4 . . .	7·05	6,570·6 =	4·71	
N . . .	19·85	18,500·2 =	23·25	
H_2O . . .	—		21·14	

If the column of weights be added up, it will be found that there is a deficiency of 6·35 grammes. The quantity of gas measured must therefore be increased to 97,158·9 cub. centims., and the corrected calculation will stand thus :—

	I.	II.	III.	IV.
	Percentage volumes, permanent gases.	Total, permanent gases.	Percentage volumes, total gases.	Percentage weights, total gases.
		cub. centims. grammes.		
CO_2 . . .	41·95	40,758·2 = 80·38	33·02	51·84
CO . . .	19·10	18,557·3 = 23·29	15·03	15·03
H . . .	12·05	11,707·7 = 1·04	9·48	0·67
CH_4 . . .	7·05	6,849·7 = 4·93	5·55	3·18
N . . .	19·85	19,286·0 = 24·26	15·62	15·65
H_2O . . .	—	27,408·4 = 21·94	21·30	13·63
Total gases		124,567·3 = 155·84	—	—

RECONCILIATION.

		C_2.	O_2.	H_2.	N_2.
CO_2 . . .	0 4195	0·2098	0·4195	—	—
CO . . .	0·1910	0·0955	0·0955	—	—
H . . .	0·1205	—	—	0·1205	—
CH_4 . . .	0·0705	0·0353	—	0·1410	—
N . . .	0·1985	—	—	—	0·1985
		0·3406	0·5150	0·2615	0·1985
		× 12	× 16	—	× 14
		= 4·087	8·240	0·2615	2·779

Multiplying again by $\dfrac{97,158\cdot9}{11,160\cdot7} = 8\cdot705$:—

	C_2. grammes.	O_2. grammes.	H_2. grammes.	N_2. grammes.
	35·58	71·73	2·28	24·19
H_2O	—	19·50	2·44	—
Totals	35·58	91·23	4·72	24·19
Originally in cordite	35·65	90·69	4·68	24·05
	− 0·07	+ 0·54	+ 0·04	+ 0·14

The heat units evolved by the explosion were, as has been already mentioned, determined in a calorimeter of the type of that described by Professor OSTWALD in his " Physico-Chemical Measurements."

The heat capacities of the explosion vessels were carefully determined, as were those of the calorimeters and their equipage, including the stirrers and the mercurial thermometers. The latter were of the differential type described by Professor OSTWALD, those I used having a range of about 8° C. Two observations for each density were sufficient if the observations were accordant. If not accordant, three were generally taken.

Not unnaturally, the observations at the higher densities were considerably more accordant than those at the lower.

Commencing with the Chilworth R. R. nitrocellulose (tubular) in Experiment 1344, 9·17 grammes were fired, the explosion vessel, when fired, being suspended in 4000 grammes of distilled water in the calorimeter, the water equivalent of the explosion vessel and the calorimeter being 680 cub. centims. It was then found that immediately before explosion the calorimeter differential thermometer showed 1°·161 (equivalent to 19°·9 C.).

		Degrees Cent.	Difference.
Temperature before explosion		1·161	—
,, 2 minutes after explosion . . .		2·600	—
,, 4 ,, ,, ,, ...		3·043	—
,, 6 ,, ,, ,, . . .		3·055	—
,, 8 ,, ,, ,, ...		3·057	− ·002
,, 10 ,, ,, ,, . . .		3·055	− ·003
,, 12 ,, ,, ,, . . .		3·052	− ·001
,, 14 ,, ,, ,, . . .		3·051	− ·003
,, 16 ,, ,, ,, . . .		3·048	− ·004
,, 18 ,, ,, ,, . . .		3·044	− ·002
,, 20 ,, ,, ,, . . .		3·042	

It will be observed that the maximum temperature reached was . . 3°·057

Subtracting temperature before explosion . . . . 1°·161

we have . . . . 1°·896

Adding correction for lost heat during rise . . . . 0°·010

1°·906

Hence $\dfrac{4680 \times 1\cdot906}{9\cdot17} = 972\cdot7$ heat units.

The temperature of the water in the outer vessel did not move during the experiment, being 21°·0 C. before and after.

A second determination of the heat, developed under the same conditions, was made in Experiment 1345, which was simply a repetition of Experiment 1344. Here, immediately before explosion, the differential thermometer gave a temperature of 0°·722 (equivalent to 19°·4 C.).

	Degrees Cent.	Difference.
Temperature at moment of explosion	0·722	—
„ 2 minutes after explosion . . .	2·050	—
„ 4 „ „ „ . . .	2·575	—
„ 6 „ „ „ . . .	2·604	—
„ 8 „ „ „ . . .	2·618	− ·001
„ 10 „ „ „ . . .	2·617	− ·003
„ 12 „ „ „ . . .	2·614	− ·002
„ 14 „ „ „ . . .	2·612	− ·003
„ 16 „ „ „ . . .	2·609	

Here the maximum temperature reached in 8 minutes was   . . .   2°·618

Subtracting temperature before explosion.   . . . .   0°·722

                                                            1°·896

Correction for loss of heat .   . . .   0°·009

                                                            1°·905

Hence units of heat developed $= \dfrac{4680 \times 1\text{·}905}{9\text{·}17} = 972\text{·}2$ units.

The previous experiment having given 972·7 heat units, the mean may be taken as 972·5. It is unnecessary to say that this degree of accuracy is exceptional, but still, considering the nature of the experiments, the accuracy, even at moderate densities, cannot be considered unsatisfactory.

Thus in Experiment 1392, at a density of 0·25, 7·737 grammes of M.D. were fired, the differential thermometer being at 2°·012 (equivalent to 18°·3 C.).   Hence

	Degrees Cent.	Difference.
Temperature at moment of explosion	2·012	
„ 2 minutes after explosion . . .	3·510	—
„ 4 „ „ „ . . .	3·707	—
„ 6 „ „ „ . . .	3·721	—
„ 8 „ „ „ . . .	3·721	—
„ 10 „ „ „ . . .	3·719	− ·002
„ 12 „ „ „ . . .	3·716	− ·003
„ 14 „ „ „ . . .	3·714	− ·002
„ 16 „ „ „ . . .	3·711	− ·003

$$\begin{aligned}
\text{Hence maximum temperature reached} \quad & 3°\text{·}721 \\
\text{Less} \quad & 2°\text{·}012 \\
\hline
& 1°\text{·}709 \\
\text{Correction} \quad & 0°\text{·}011 \\
\hline
& 1°\text{·}720
\end{aligned}$$

$$\text{Hence units of heat} = \frac{4680 \times 1\text{·}720}{7\text{·}737} = 1039\text{·}2 \text{ units.}$$

The repeat Experiment 1393 gave

$$\text{Units of heat} = \frac{4680 \times 1\text{·}720}{7\text{·}737} = 1030\text{·}2 \text{ units.}$$

Again, in Experiment 1390, at the same density, 0·25, the same number of grammes were fired, the differential thermometer immediately before the explosion being at 0°·581 (equivalent to 18°·6 C.). Hence :—

	Degrees Cent.	Difference.
Temperature at moment of explosion	0·581	
„ 2 minutes after explosion . . .	2·362	—
„ 4 „ „ „ . . .	2·599	—
„ 6 „ „ „ . . .	2·617	—
„ 8 „ „ „ . . .	2·618	—
„ 10 „ „ „ . . .	2·614	− ·004
„ 12 „ „ „ . . .	2·611	− ·003
„ 14 „ „ „ . . .	2·607	− ·004
„ 16 „ „ „ . . .	2·603	− ·004

$$
\begin{array}{lr}
 & \text{C.} \\
\text{Hence maximum temperature reached} \ . \ . \ . \ . & 2°{\cdot}618 \\
\text{Less} \ . \ . \ . \ . \ . \ . \ . \ . \ . & 0°{\cdot}581 \\
\hline
 & 2°{\cdot}037 \\
\text{Add correction} \ . \ . \ . \ . \ . \ . \ . & 0°{\cdot}012 \\
\hline
 & 2°{\cdot}049
\end{array}
$$

Hence units of heat $= \dfrac{4680 \times 2{\cdot}049}{7{\cdot}737} = 1239{\cdot}5.$

The repeat Experiment No. 1391 gave

Units of heat $= \dfrac{4680 \times 2{\cdot}060}{7{\cdot}737} = 1246{\cdot}2.$

To illustrate the remark I made as to increase of accuracy when taking the calorimetric observations at the higher densities, I give the whole of the observations on this point with Mark I cordite. Thus, at the density of 0·05 the three observations were, respectively, 1265·1, 1303·0, 1248·8, or a mean of 1272·3 units. With density 0·1 the three observations were 1275·8, 1240·5, 1235·7, or a mean of 1250·7 units. Density 0·15 gave 1259·7, 1247·2, 1242·7, or a mean of 1249·9. With density 0·20, 1245·2, 1246·5, 1241·0, or a mean of 1244·2. Density 0·25, 1246·2, 1239·5, and 1241·3, giving a mean of 1242·3. 0·3 density gave 1276·9, 1280·0, 1264·0, mean 1273·6: for 0·4, 1305·0 and 1294·3 or 1299·7 mean, and for 0·45, 1326·3 and 1320·0 or mean 1323·2.

We are now in a position to give in a tabular form the result of the series of experiments on the three explosives fired under a variety of densities and pressures, and with regard to which the essential constants have been determined.

These tables give :—

(1.) The densities under which the various charges were fired.
(2.) The volumes of permanent gases generated at 0° C. and 760 millims. of barometric pressure per gramme of explosive.
(3.) The total volume of gas per gramme, aqueous vapour being included.
(4.) The percentage volumes of permanent gases.
(5.) The percentage volumes of the total gases.
(6.) The percentage weights of the total gases.
(7.) The pressures at each density in tons per sq. inch.
(8.) The same pressures in atmospheres.
(9.) The units of heat determined, the water being fluid.
(10.) The units of heat, water being gaseous.
(11.) The specific heat of the products of explosion for each density.
(12.) The comparative temperatures of explosion determined by dividing the units of heat (water gaseous) by the specific heats in (11).
(13.) The comparative potential energy, the highest energy determined being taken as unity.

CORDITE, MARK I.

	0·05	0·10	0·15	0·20	0·25	0·30	0·40	0·50
Density of charge exploded	0·05	0·10	0·15	0·20	0·25	0·30	0·40	0·50
Volumes of permanent gases per gramme	678·0	685·1	690·9	711·2	691·9	662·4	644·9	623·6
Volumes of total gases per gramme	877·8	870·7	877·9	888·7	871·3	833·6	820·0	798·8
Percentage volumes of permanent gases CO_2	27·15	28·05	29·10	30·65	31·75	35·70	38·30	41·95
CO	34·35	33·10	31·90	29·65	28·90	24·80	22·65	19·10
H	17·50	19·25	19·50	19·55	18·95	17·50	14·80	12·05
CH_4	0·30	0·45	0·60	1·55	1·60	3·30	5·05	7·05
N	20·70	19·15	18·90	18·60	18·80	18·70	19·20	19·85
Percentage volumes of total gases CO_2	20·97	22·06	22·99	24·53	25·25	28·37	30·13	33·02
CO	26·53	26·03	25·20	23·73	22·98	19·71	17·81	15·03
H	13·52	15·14	15·41	15·64	15·07	13·91	11·64	9·48
CH_4	0·23	0·36	0·47	1·24	1·27	2·62	3·97	5·55
N	15·99	15·06	14·93	14·88	14·95	14·86	15·10	15·62
H_2O	22·76	21·35	21·00	19·98	20·48	20·53	21·35	21·30
Percentage weights of total gases CO_2	36·10	38·24	39·62	42·91	42·82	47·03	48·68	51·84
CO	29·00	28·70	27·69	25·51	24·80	20·78	18·32	15·03
H	1·14	1·16	1·21	1·25	1·16	1·04	0·85	0·67
CH_4	0·18	0·21	0·31	0·79	0·78	1·58	2·34	3·18
N	17·63	16·62	16·37	16·61	16·17	15·68	15·57	15·65
H_2O	15·95	15·07	14·80	12·93	14·27	13·89	14·24	13·63
Pressure in tons per sq. inch	2·9	7·8	11·49	17·2	21·08	30·5	41·4	52·9
Pressure in atmospheres	442·1	1189·0	1751·5	2621·9	3213·3	4649·3	6310·8	8063·8
Units of heat, water fluid	1272·3	1250·7	1249·9	1244·2	1242·3	1273·6	1299·7	1360·0
Units of heat, water gaseous	1186·8	1169·9	1170·6	1174·9	1165·8	1199·2	1223·4	1287·0
Specific heat	0·23040	0·22918	0·23005	0·22863	0·22920	0·22804	0·22668	0·22385
Temperatures of explosion	5151°·1	5104°·7	5088°·4	5138°·9	5086°·4	5258°·7	5397°·0	5749°·4
Comparative potential energy	0·9825	0·9822	0·9788	0·9739	0·9689	0·9619	0·9677	1·0000

M.D. CORDITE.

	0·05	0·10	0·15	0·20	0·25	0·30	0·40	0·45
Density of charge exploded	0·05	0·10	0·15	0·20	0·25	0·30	0·40	0·45
Volumes of permanent gases per gramme	781·8	788·4	799·9	769·1	745·5	735·0	692·7	676·3
Volumes of total gases per gramme	955·4	946·4	933·8	915·5	888·6	875·3	831·2	810·6
Percentage volumes of permanent gases — CO_2	18·15	20·10	21·50	23·80	26·75	29·40	33·40	36·60
CO	42·60	40·70	38·90	36·30	33·65	31·10	27·25	24·80
H	23·15	23·10	22·70	21·70	19·80	17·75	14·45	11·90
CH_4	0·35	1·00	1·90	3·40	4·65	6·55	9·30	10·70
N	15·75	15·10	15·00	14·80	15·15	15·20	15·60	16·00
Percentage volumes of total gases — CO_2	14·85	16·74	17·95	19·99	22·45	24·69	27·83	30·56
CO	34·87	33·90	32·48	30·50	28·23	26·12	22·71	20·71
H	18·95	19·24	18·95	18·23	16·61	14·91	12·04	9·94
CH_4	0·29	0·83	1·59	2·86	3·90	5·50	7·75	8·94
N	12·89	12·57	12·53	12·43	12·71	12·76	13·00	13·36
H_2O	18·15	16·72	16·50	15·99	16·10	16·02	16·67	16·49
Percentage weights of total gases — CO_2	27·69	30·82	32·80	36·08	39·30	42·07	45·83	48·75
CO	41·38	39·71	38·11	35·02	31·45	28·32	23·78	21·02
H	1·62	1·61	1·76	1·50	1·32	1·16	0·90	0·72
CH_4	0·18	0·55	1·06	1·88	2·48	3·41	4·65	5·19
N	15·32	14·74	14·69	14·32	14·19	13·91	13·65	13·59
H_2O	13·81	12·57	11·58	11·20	11·26	11·13	11·19	10·73
Pressure in tons per sq. inch	2·7	6·9	10·2	15·2	20·7	27·62	38·1	43·22
Pressure in atmospheres	411·6	1051·8	1554·8	2317·0	3155·4	4210·3	5807·8	6587·3
Units of heat, water fluid	1035·9	1029·8	1014·7	1034·7	1041·4	1067·2	1150·5	1190·0
Units of heat, water gaseous	961·9	962·4	952·6	974·7	981·1	1007·6	1090·5	1132·5
Specific heat	0·23714	0·23552	0·23840	0·23418	0·23198	0·23082	0·22869	0·22529
Temperatures of explosion	4056°·2	4086°·7	3995°·8	4119°·9	4220°·6	4365°·3	4768°·4	5026°·8
Comparative potential energy	0·8401	0·8282	0·8209	0·8173	0·8215	0·8335	0·8639	0·8842

NITRO CELLULOSE.

		0·05	0·10	0·15	0·20	0·222	0·29	0·30	0·40	0·45
Density of charge exploded		0·05	0·10	0·15	0·20	0·222	0·29	0·30	0·40	0·45
Volumes of permanent gases per gramme		814·7	804·8	804·4	768·9	759·2	737·8	737·9	690·1	680·9
Volumes of total gases per gramme		993·1	969·3	970·1	929·9	922·3	888·5	882·2	846·8	816·3
Percentage volumes of permanent gases	CO_2	17·90	19·85	20·85	22·90	25·10	27·85	28·06	33·40	35·00
	CO	43·45	41·45	40·65	38·80	36·55	34·30	34·02	27·25	27·85
	H	24·40	24·90	23·85	21·75	20·25	17·10	17·16	14·45	12·65
	CH_4	0·60	0·85	1·90	3·50	4·70	7·30	7·41	9·30	11·10
	N	13·65	12·95	12·75	13·05	13·40	13·45	13·35	15·60	13·40
Percentage volumes of total gases	CO_2	14·68	16·48	17·37	18·94	20·66	23·13	23·47	27·83	29·16
	CO	35·63	34·42	33·85	32·08	30·09	28·48	28·46	22·71	23·20
	H	20·01	20·67	19·86	17·99	16·67	14·20	14·35	12·04	10·54
	CH_4	0·49	0·71	1·58	2·89	3·87	6·06	6·20	7·75	9·25
	N	11·19	10·75	10·62	10·79	11·03	11·17	11·17	13·00	11·16
	H_2O	18·00	16·97	16·72	17·31	17·68	16·96	16·35	16·67	16·69
Percentage weights of total gases	CO_2	28·19	31·03	32·18	34·46	36·88	40·11	40·20	45·83	47·26
	CO	43·53	41·24	39·91	37·14	34·15	31·42	30·98	23·78	23·92
	H	1·74	1·76	1·68	1·48	1·36	1·12	1·12	0·90	0·79
	CH_4	0·34	0·48	1·07	1·92	2·52	3·82	3·86	4·65	5·45
	N	13·71	12·92	12·54	12·52	12·56	12·36	12·35	13·65	11·54
	H_2O	12·49	12·57	12·62	12·48	12·53	11·17	11·49	11·19	11·04
Pressure in tons per sq. inch		3·35	6·26	10·4	14·41	16·47	21·5	20·54	34·9	40·5
Pressure in atmospheres		510·7	954·2	1585·3	2196·6	2510·6	3277·4	3131·0	5320·0	6173·6
Units of heat, water fluid		896·1	869·8	887·8	929·3	931·0	970·2	972·5	1021·4	1036·9
Units of heat, water gaseous		829·2	802·4	820·2	862·4	863·9	910·3	910·9	961·4	977·7
Specific heat		0·23772	0·23869	0·23871	0·23642	0·23554	0·23126	0·23201	0·22869	0·22828
Temperatures of explosion		3488°·1	3361°·7	3435°·9	3647°·8	3667°·7	3936°·2	3926°·1	4203°·9	4282°·9
Comparative potential energy		0·7389	0·7251	0·7220	0·7368	0·7438	0·7568	0·7592	0·7659	0·7686

If the figures given in these tables be carefully examined, it will be observed that in the three explosives the transformation on firing appears in all to follow the same general laws.

Thus in all three there is, with increase of pressure, at first a slight increase, afterwards a steady decrease in the volume of permanent gases produced.

This increase in the total gases is much less marked with cordite, and in the case of M.D. and nitrocellulose there is practically a steady decrease in the volume of the total gases.

In all three explosives there is, with increased pressure, a large increase in the volume of carbonic anhydride and a large decrease in the volume of carbonic monoxide.

In the case of hydrogen, this decrease of volume with increase of pressure is very great, while with methane, the percentage which with low pressures is quite insignificant, very rapidly increases and at the highest density is from twenty to thirty times greater than the lowest density.

There are some variations in the percentages of nitrogen and H_2O, but on the whole these constituents may be considered to be nearly constant.

The units of heat with a slight decline at first afterwards increase and somewhat rapidly at the highest pressures.

But the changes which take place under different pressures are more readily appreciated if the observations are graphically recorded by means of curves.

Accordingly in Plate 5 I have given for three explosives the pressures in tons per sq. inch and in atmospheres, deduced from the experiments under consideration, and which pressures vary from about 3 tons per sq. inch (457 atmospheres) to (in the case of Mark I cordite) 53 tons per sq. inch (8078 atmospheres).

It will be observed also that from densities of about 0·25 upwards the curve expressing the relation of pressure to density, both in the Mark I cordite and in the M.D., differs inappreciably from a straight line. This remark also appears to be, in some degree, corroborated by an experiment I once made at a density of unity, and which gave a pressure of about 112* tons per sq. inch (17,070 atmospheres).

With nitrocellulose there appears, at high densities, to be a tendency to detonate, from which tendency Mark I cordite appears to be free. By way of showing the enormous superiority of the new explosives as regards potential energy, I have added to Plate 5 the curve showing the relation of pressure to density of fired gunpowder.

In Plate 6 there are three sets of curves :—(1) The changes in the volumes of the permanent gases due to increase of density ; (2) The changes in the volumes of the total gases which do not differ very greatly from those of the permanent gases ; and (3) The changes in the units of heat at different densities (water fluid).

It may be noted that, while at pressures under 20 tons per sq. inch the heat

* On the occasion referred to, I was not sure that the pressure might not be higher, as there was considerable friction between the piston and the cylinder, due to compression of the gauge.

developed does not vary greatly; at higher pressures the heat increases considerably, thus compensating for the loss of potential energy due to the decrement in the volume of gas generated.

Plates 7, 8 and 9 show graphically the great changes that take place in the decomposition of the gases in passing from densities of 0·05 to 0·45.

In all, carbon monoxide and dioxide change places, the two gases having equal volumes in the case of cordite 24·2 per cent. at a density of 0·19, in the case of M.D. 25·5 per cent. at a density of 0·32, and with nitrocellulose 26 per cent. at a density of 0·36.

The changes with hydrogen and methane are equally striking, the hydrogen in cordite falling from a maximum of nearly 16 per cent. in volumes to about 9·5, while the methane increases from about 0·2 per cent. to about 5·5 per cent. In M.D. the volumes of hydrogen fall from about 19 per cent. to about 10·4 per cent., while the volume of methane increases from about 0·3 per cent. to nearly 9 per cent., and in nitrocellulose the volume of hydrogen falls from 20·7 per cent. to about 11 per cent., the methane increasing from 0·5 per cent. to a little over 9 per cent.

In the tables I have submitted it will be observed that the specific heats and the temperatures of explosion have been given, but in regard to temperatures so far above those in regard to which accurate observations have been made the figures I give can only be taken as provisional. The specific heats of the various gases have been taken at the values usually assigned to them. Of course, it cannot be assumed that these specific heats remain unchanged over the wide range of temperature necessary, although I believe it has been found that the specific heats of some permanent gases such as nitrogen and oxygen are but slightly altered up to 800° C.

The temperatures of explosion which, as I have said, can only be taken as provisional, have been obtained by dividing the units of heat (water gaseous) by the specific heats, and, although provisional, can safely be used in comparing the temperatures of explosion of the three explosives. The temperatures of explosion, for example, of cordite and nitrocellulose at the density of 0·20 may tolerably safely be taken to be in the ratio of 51 to 36.

I am, from other considerations, inclined to believe that the temperatures I have obtained and given in the tables are not very far removed from the truth. I tried with cordite to confirm the results by using the equation of dilatability of gases. At the high pressures the results were satisfactory, but quite the reverse at the lower densities.

The comparative approximate potential energies are obtained by multiplying the volume of gas produced by the temperature of explosion. The means for the three explosives are respectively: cordite, 0·9762; M.D., 0·8387; nitrocellulose, 0·7464. The highest potential energy (taken as unity), it will be noted, was obtained from cordite at a density of 0·5.

I submit that the wide differences in the transformation of the three explosives

with which I have experimented justify the conclusion at which Sir F. ABEL and I arrived with respect to gunpowder, viz., that any attempt to define by a chemical equation the nature of the metamorphosis which one explosive may be considered to undergo would only be calculated to convey an erroneous impression as to the *definite nature* of the chemical results and *their uniformity* under different conditions.

The apparatus shown in Plate 4 was employed for two purposes, (1) to determine the time for the complete ignition of various explosives, or for various forms and thicknesses of the same explosives; (2) to determine the rate at which the exploded gases part with their heat to the walls of the vessel in which they are enclosed.

The high and low speeds that can be given to the drum permit these two observations to be made by a single experiment. Thus, in Plate 10, I show the commencement and part of the curves of two experiments, the one (fig. 1) fired at a pressure of a little over 12 tons per sq. inch (1829 atmospheres), the other (fig. 2) nearly 18 tons (2744 atmospheres). At the point "A" the charge is fired, and it will be noted that the circumference of the drum is travelling at about 40 inches per second. From fig. 2 it will be seen that at 2 seconds after firing the speed has, in this experiment, been reduced to about an inch per second.

The times required for the completion of ignition are given in Plate 11, and are obtained from the curves shown on Plate 10 and from two similar curves. The vertical scale in Plate 11 for the three last densities is doubled to make them accord with density 0·1, the spring employed in that experiment being half the strength of that used for the last three.

I may point out that when fired in close vessels the rate of combustion of the explosives, even in the cord form, appears to be very constant, the increase of pressure apparently nearly compensates for the reduction of surface, the differences in time of burning being due to want of uniformity in the lighting, which in many cases is very variable. This is illustrated by comparing the times of ignition of densities 0·15 and 0·2 in Plate 11, where the total time from firing to complete ignition is less for density 0·15 than for density 0·2. In reality, however, after complete lighting the latter is burning quicker, as may be seen by comparing the angles made by the curves with the axis of abscissæ.

But this question is too large to enter into fully in the present paper. I therefore only give the times of approximate complete combustion of cordite and M.D. cordite of different diameters when exploded at a pressure of about 9 tons on the square inch.

Diameter of cordite.	Time of burning, seconds.	Diameter of M.D.	Time of burning, seconds.
0·033	0·0163	—	—
0·045	0·0172	—	—
0·091	0·0207	—	—
0·181	0·0274	0·192	0·0377
0·266	0·0337	0·235	0·0480
0·343	0·0395	0·263	0·0547
0·482	0·0499	0·318	0·0679
0·577	0·0570	—	—

Comparing the times of burning of 0·2 cordite and rifle cordite, the times are approximately as follows :—

0·2 cordite.		Rifle cordite.	
Tons per sq. inch.	Seconds.	Tons per sq. inch.	Seconds.
3·5	0·03844	3·5	0·00972
10·0	0·01896	10·0	0·00553
11·5	0·01700	11·5	0·00498

The rates of cooling of cordite (charges and densities being as stated) are shown in Plate 12, the interior surface of the explosive vessel being 54·9 sq. inches (354·3 sq. centims.). The communication of heat to the vessel is extraordinarily rapid. The pressure and approximately the temperature of the exploded gases is in the case of

Density 0·1 (32 grammes) reduced to one half in 0·87 second, and to one quarter in 2·70 seconds.

Density 0·15 (48 grammes) reduced to one half in 0·93 second, and to one quarter in 2·82 seconds.

Density 0·20 (64 grammes) reduced to one half in 1·54 seconds, and to one quarter in 3·83 seconds.

Density 0·25 (80 grammes) reduced to one half in 2·40 seconds, and to one quarter in 6·04 seconds.

1020·6 grammes of the same cordite fired at a density of 0·1 in a vessel whose interior surface was 3271 sq. centims. reduced its pressure to one half in 3·1 seconds, to one fourth in 10 seconds.

1247·4 grammes fired at a density of 0·12 in the same vessel had the pressure reduced to one half in 4·2 seconds, and to one quarter in 13·8 seconds.

1360·8 grammes fired at a density of 0·131 in the same vessel recorded a pressure of one half in 6·3 seconds, and of one quarter in 31 seconds.

I venture to allude to two other points of interest. I have always thought it probable that the dissociation, for example, of carbonic dioxide into carbonic monoxide and oxygen might be very greatly modified or extinguished by the extremely high pressure at which my experiments have been made ; and I thought it possible that, if dissociation did take place, some indication of the re-formation of carbonic dioxide would appear in the cooling curves, which have been obtained under a variety of conditions and pressures. These curves, however, are singularly free from any indication of disturbance, so that, if any recombination does take place, it has no effect on the extremely regular coolings to which I have alluded, and would seem to prove that the re-formation of CO_2 and H_2O must take place gradually and in no case *per saltum.* I have found also, and this point is of some interest, that gases I have taken from the chamber of a 9·2-inch gun immediately after firing have, when corrected for the air with which they are mixed, the same composition as those which have been fired under similar densities in a close vessel.

The experiments I have made on erosion with the three explosives referred to in this paper, and on some others, have satisfied me that the amount of absolute erosion is governed practically entirely by the heat developed by the explosion. I had thought that increase of pressure would considerably increase the amount of erosion, but in experiments carried on with cordite and nitrocellulose under pressures varying from 5 tons to 32 tons per sq. inch the erosion was practically entirely independent of the pressure both for the cordite and the nitrocellulose. The results of these experiments are given in Plate 13.

APPENDIX.

Abstract of Experiments Referred to in Paper.

CORDITE MARK I.

Experiment 1380.—Fired in explosion vessel Q, 16·75 grammes of Mark I cordite. Density of charge 0·05.

Pressure 2·9 tons per sq. inch (442·1 atmospheres).

Permanent gases 11,186·7 cub. centims. at 0° C. and 760 millims.

Aqueous vapour 3296·6 cub. centims.

RECONCILIATION.

	C.	O.	H.	N.
	grammes	grammes	grammes	grammes
Found by analysis	3·72	9·47	0·47	2·91*
Originally in cordite . . .	3·68	9·35	0·48	2·48
Differences	+ 0·04	+ 0·12	− 0·01	+ 0·43

* The N and O contained in air in cylinder not taken into account.

Experiment 1383.—Fired in explosion vessel Q, 32·73 grammes of Mark I cordite. Density of charge 0·10.

Pressure 7·8 tons per sq. inch (1189·0 atmospheres).

Permanent gases 23,124·7 cub. centims. at 0° C. and 760 millims.

Aqueous vapour 6277·2 cub. centims. at 0° C. and 760 millims.

RECONCILIATION.

	C.	O.	H.	N.
	grammes	grammes	grammes	grammes
Found by analysis	7·66	19·26	0·98	5·56
Originally in cordite . . .	7·53	19·13	0·98	5·08
Differences	+ 0·13	+ 0·13	0·00	+ 0·48

Experiment 1386.—Fired in explosion vessel Q, 47·77 grammes of Mark I cordite. Density of charge 0·15.

Pressure 11·49 tons per sq. inch (1751·5 atmospheres).

Permanent gases 33,646·2 cub. centims. at 0° C. and 760 millims.

Aqueous vapour 9104·7 cub. centims. at 0° C. and 760 millims.

RECONCILIATION.

	C.	O.	H.	N.
	grammes	grammes	grammes	grammes
Found by analysis	11·14	28·26	1·44	7·98
Originally in cordite . . .	11·20	28·48	1·47	7·56
Differences	− 0·06	− 0·22	− 0·03	+ 0·42

Experiment 1371.—Fired in explosion vessel Q, 63·96 grammes of Mark I cordite. Density of charge 0·20.

Pressure 17·2 tons per sq. inch (2621·9 atmospheres).

Permanent gases 46,440·3 cub. centims. at 0° C. and 760 millims.

Aqueous vapour 11,594·1 cub. centims. at 0° C. and 760 millims.

RECONCILIATION.

	C.	O.	H.	N.
	grammes	grammes	grammes	grammes
Found by analysis	15·45	38·59	1·98	10·86
Originally in cordite . . .	15·02	38·18	1·98	10·14
Differences	+ 0·43	+ 0·41	0·00	+ 0·72

Experiment 1389.—Fired in explosion vessel Q, 80·3 grammes of Mark I cordite.   Density of charge 0·25.

Pressure 21·08 tons per sq. inch (3213·3 atmospheres).

Permanent gases 55,834·4 cub. centims. at 0° C. and 760 millims.

Aqueous vapour 14,480 cub. centims. at 0° C. and 760 millims.

RECONCILIATION.

	C.	O.	H.	N.
	grammes	grammes	grammes	grammes
Found by analysis	18·69	47·33	2·40	13·17
Originally in cordite . . .	18·76	47·70	2·46	12·67
Differences	− 0·07	− 0·37	− 0·06	+ 0·50

Experiment 1375.—Fired in explosion vessel Q, 95·94 grammes of Mark I cordite.   Density of charge 0·30.

Pressure 30·5 tons per sq. inch (4649·3 atmospheres).

Permanent gases 64,453·7 cub. centims. at 0° C. and 760 millims.

Aqueous vapour 16,653·4 cub. centims. at 0° C. and 760 millims.

RECONCILIATION.

	C.	O.	H.	N.
	grammes	grammes	grammes	grammes
Found by analysis	22·11	56·35	2·88	15·12
Originally in cordite . . .	22·31	56·71	2·93	15·05
Differences	− 0·20	− 0·36	− 0·05	+ 0·07

Experiment 1497.—Fired in explosion vessel Q, 124·67 grammes of Mark I cordite.   Density of charge 0·40.

Pressure 41·4 tons per sq. inch (6310·8 atmospheres).

Permanent gases 80,403·1 cub. centims. at 0° C. and 760 millims.

Aqueous vapour 21,832 cub. centims. at 0° C. and 760 millims.

RECONCILIATION.

	C.	O.	H.	N.
	grammes	grammes	grammes	grammes
Found by analysis	28·54	72·79	3·74	19·36
Originally in cordite . . .	28·67	72·89	3·76	19·35
Differences	− 0·13	− 0·10	− 0·02	+ 0·01

Experiment 1496.—Fired in explosion vessel Q, 155·84 grammes of Mark I cordite. Density of charge 0·5.

Pressure 52·84 tons per sq. inch (8063·8 atmospheres).

Permanent gases 97,158·9 cub. centims. at 0° C. and 760 millims.

Aqueous vapour 26,291 cub. centims. at 0° C. and 760 millims.

RECONCILIATION.

	C.	O.	H.	N.
	grammes	grammes	grammes	grammes
Found by analysis	35·58	90·52	4·63	24·19
Originally in cordite . . .	35·65	90·69	4·68	24·05
Differences	− 0·07	− 0·17	− 0·05	+ 0·14

Experiment 1387.—Fired in explosion vessel Q, 16 grammes M.D. Density of charge 0·05.

Pressure 2·7 tons per sq. inch (411·6 atmospheres).

Permanent gases 12,899·8 cub. centims. at 0° C. and 760 millims.

Aqueous vapour 2861·2 cub. centims. at 0° C. and 760 millims.

RECONCILIATION.

	C.	O.	H.	N.
	grammes	grammes	grammes	grammes
Found by analysis	4·24	9·34	0·53	2·55*
Originally in M.D.	4·66	9·53	0·53	1·97
Differences	− 0·42	− 0·19	0·00	+ 0·57

* Chiefly due to air in explosion vessel.

Experiment 1388.—Fired in explosion vessel Q, 31·98 grammes M.D. Density of charge 0·10.

Pressure 6·9 tons per sq. inch (1051·8 atmospheres).

Permanent gases 25,621·0 cub. centims. at 0° C. and 760 millims.

Aqueous vapour 5145·1 cub. centims. at 0° C. and 760 millims.

RECONCILIATION.

	C.	O.	H.	N.
	grammes	grammes	grammes	grammes
Found by analysis	8·51	18·53	1·04	4·85*
Originally in M.D.	9·12	18·66	1·03	4·49
Differences	− 0·61	− 0·13	+ 0·01	+ 0·36

* Including N in air.

Experiment 1357.—Fired in explosion vessel Q, 47·97 grammes M.D.   Density of charge 0·15.
Pressure 10·2 tons per sq. inch (1554·8 atmospheres).
Permanent gases 38,458·3 cub. centims. at 0° C. and 760 millims.
Aqueous vapour 7600·8 cub. centims. at 0° C. and 760 millims.

RECONCILIATION.

	C.	O.	H.	N.
	grammes	grammes	grammes	grammes
Found by analysis	13·58	28·00	1·59	7·24
Originally in M.D.	13·53	28·13	1·66	6·69
Differences	+ 0·05	− 0·13	− 0·07	+ 0·55

Experiment 1356.—Fired in explosion vessel Q, 63·96 grammes M.D.   Density of charge 0·20.
Pressure 15·2 tons per sq. inch (2317·0 atmospheres).
Permanent gases 50,229·8 cub. centims. at 0° C. and 760 millims.
Aqueous vapour 9,558·7 cub. centims. at 0° C. and 760 millims.

RECONCILIATION.

	C.	O.	H.	N.
	grammes	grammes	grammes	grammes
Found by analysis	17·17	37·00	2·14	9·32
Originally in M.D.	17·66	36·74	2·17	8·74
Differences	− 0·49	+ 0·26	− 0·03	+ 0·58

Experiment 1370.—Fired in explosion vessel Q, 79·95 grammes of M.D.   Density of charge 0·25.
Pressure 20·74 tons per sq. inch (3155·4 atmospheres).
Permanent gases 60,611·2 cub. centims. at 0° C. and 760 millims.
Aqueous vapour 11,631·4 cub. centims. at 0° C. and 760 millims.

RECONCILIATION.

	C.	O.	H.	N.
	grammes	grammes	grammes	grammes
Found by analysis	21·21	46·17	2·62	11·52
Originally in M.D.	21·99	45·74	2·71	10·86
Differences	− 0·78	+ 0·43	− 0·09	+ 0·66

Experiment 1354.—Fired in explosion vessel Q, 98·94 grammes of M.D. cordite. Density of charge 0·3.
Pressure 27·62 tons per sq. inch (4210·3 atmospheres).
Permanent gases 72,768·0 cub. centims. at 0° C. and 760 millims.
Aqueous vapour 13,885·5 cub. centims. at 0° C. and 760 millims.

RECONCILIATION.

	C.	O.	H.	N.
	grammes	grammes	grammes	grammes
Found by analysis	26·22	56·81	3·25	13·88
Originally in M.D.	27·05	56·26	3·33	13·36
Differences	− 0·83	+ 0·55	− 0·08	+ 0·52

Experiment 1405.—Fired in explosion vessel R, 128·48 grammes of M.D. cordite. Density of charge 0·40.
Pressure 38·1 tons per sq. inch (5807·8 atmospheres).
Permanent gases 89,410·2 cub. centims. at 0° C. and 760 millims.
Aqueous vapour 17,887·2 cub. centims. at 0° C. and 760 millims.

RECONCILIATION.

	C.	O.	H.	N.
	grammes	grammes	grammes	grammes
Found by analysis	33·63	73·06	4·25	17·50
Originally in M.D.	35·87	73·37	4·06	15·18
Differences	− 2·24	− 0·31	+ 0·19	+ 2·32

Experiment 1417.—Fired in explosion vessel Q, 143·91 grammes of M.D. cordite. Density of charge 0·45.
Pressure 43·22 tons per sq. inch (6587·3 atmospheres).
Permanent gases 97,589·5 cub. centims. at 0° C. and 760 millims.
Aqueous vapour 19,394·0 cub. centims. at 0° C. and 760 millims.

RECONCILIATION.

	C.	O.	H.	N.
	grammes	grammes	grammes	grammes
Found by analysis	37·88	82·42	4·64	19·59
Originally in M.D.	39·06	81·24	4·80	19·29
Differences	− 1·18	+ 1·18	− 0·16	+ 0·30

Experiment 1339.—Fired in explosion vessel L_2, 41·5 grammes of Rottweil R. R.   Density of charge 0·05.

Pressure 3·35 tons per sq. inch (510·7 atmospheres).

Permanent gases 33,811·8 cub. centims. at 0° C. and 760 millims.

Aqueous vapour 7402·8 cub. centims. at 0° C. and 760 millims.

RECONCILIATION.

	C.	O.	H.	N.
	grammes	grammes	grammes	grammes
Found by analysis	11·26	24·49	1·44	5·79
Originally in R. R.	11·59	23·71	1·32	4·91
Differences	− 0·33	+ 0·78	+ 0·12	+ 0·88

Experiment 1340.—Fired in explosion vessel L_2, 83 grammes of Rottweil R. R.   Density of charge 0·10.

Pressure 6·26 tons per sq. inch (954·2 atmospheres).

Permanent gases 66,802·6 cub. centims. at 0° C. and 760 millims.

Aqueous vapour 13,646·7 cub. centims. at 0° C. and 760 millims.

RECONCILIATION.

	C.	O.	H.	N.
	grammes	grammes	grammes	grammes
Found by analysis	22·38	48·60	2·81	10·85
Originally in R. R.	23·17	47·40	2·62	9·81
Differences	− 0·79	+ 1·20	+ 0·19	+ 1·04*

* Partly due to air in explosion vessel.

Experiment 1341.—Fired in explosion vessel Q, 47·97 grammes of Rottweil R. R.   Density of charge 0·15.

Pressure 10·4 tons per sq. inch (1585·3 atmospheres).

Permanent gases 38,585·8 cub. centims. at 0° C. and 760 millims.

Aqueous vapour 7949·2 cub. centims. at 0° C. and 760 millims.

RECONCILIATION.

	C.	O.	H.	N.
	grammes	grammes	grammes	grammes
Found by analysis	13·15	28·45	1·66	6·17
Originally in R. R.	13·39	27·40	1·52	5·38
Differences	− 0·24	+ 1·05	+ 0·14	+ 0·79

Experiment 1342.—Fired in explosion vessel L$_2$, 166 grammes of Rottweil R. R. Density of charge 0·20.
Pressure 14·41 tons per sq. inch (2196·6 atmospheres).
Permanent gases 127,643·1 cub. centims. at 0° C. and 760 millims.
Aqueous vapour 26,721·6 cub. centims. at 0° C. and 760 millims.

RECONCILIATION.

	C.	O.	H.	N.
	grammes	grammes	grammes	grammes
Found by analysis	44·7	96·5	5·7	20·9
Originally in R. R.	46·6	95·6	5·4	19·7
Differences	– 1·9	+ 0·9	+ 0·3	+ 1·2

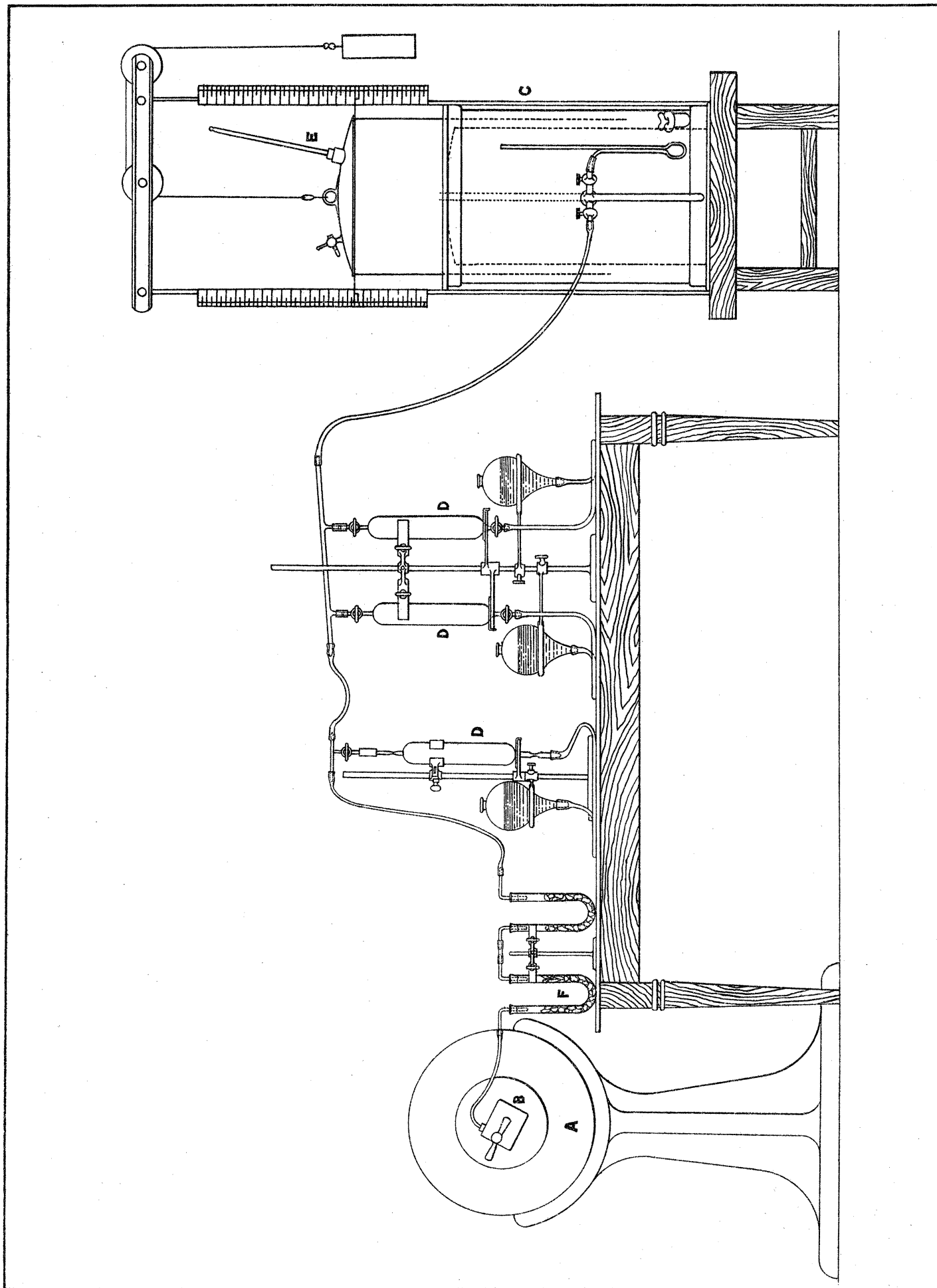*Experiment* 1338.—Fired in explosion vessel Q, 70·99 grammes of Rottweil R. R. Density of charge 0·222.
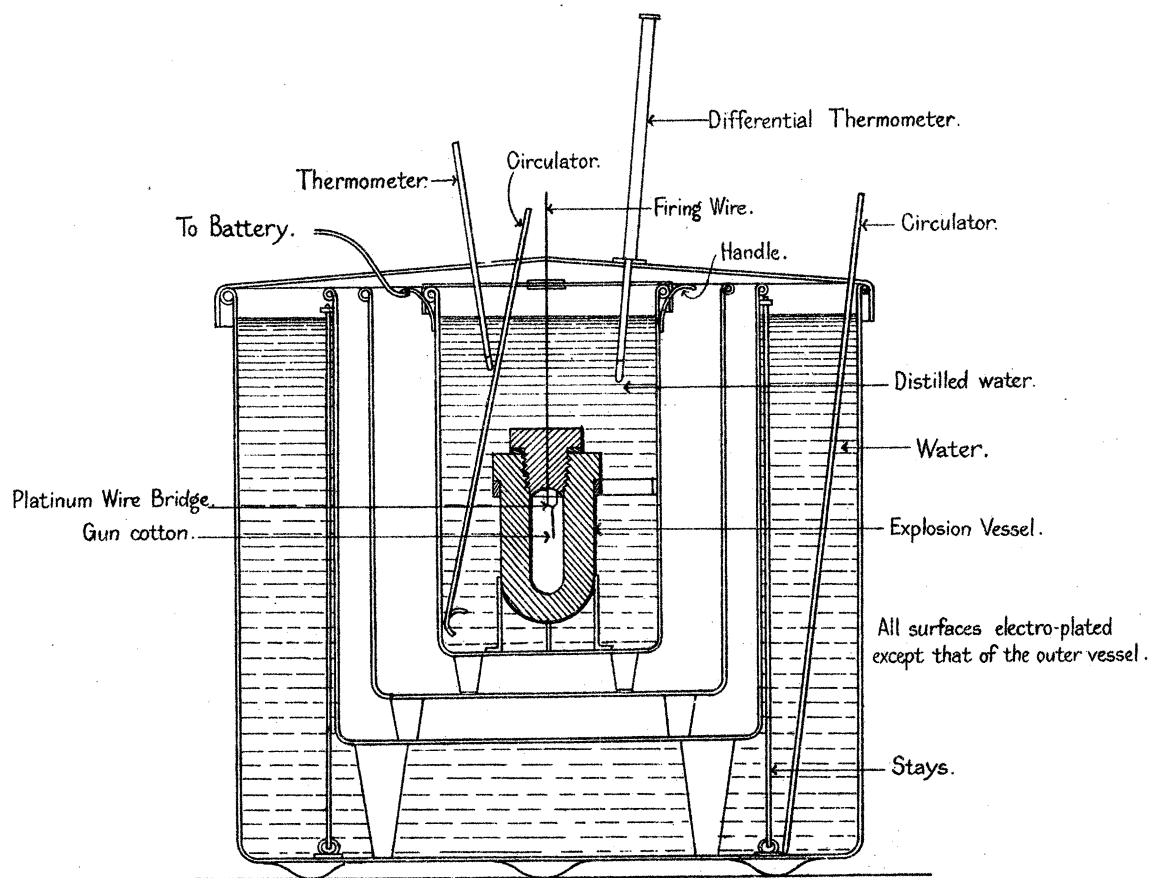Pressure 16·47 tons per sq. inch (2510·6 atmospheres).
Permanent gases 53,898·2 cub. centims. at 0° C. and 760 millims.
Aqueous vapour 11,576·7 cub. centims. at 0° C. and 760 millims.

RECONCILIATION.

	C.	O.	H.	N.
	grammes	grammes	grammes	grammes
Found by analysis	19·22	41·76	2·46	9·06
Originally in R. R.	19·82	40·55	2·25	8·40
Differences	– 0·60	+ 1·21	+0·21	+0·66

Experiment 1337.—Fired in explosion vessel Q, 92·74 grammes of Rottweil R. R. Density of charge 0·29.
Pressure 21·5 tons per sq. inch (3277·4 atmospheres).
Permanent gases 68,427·3 cub. centims. at 0° C. and 760 millims.
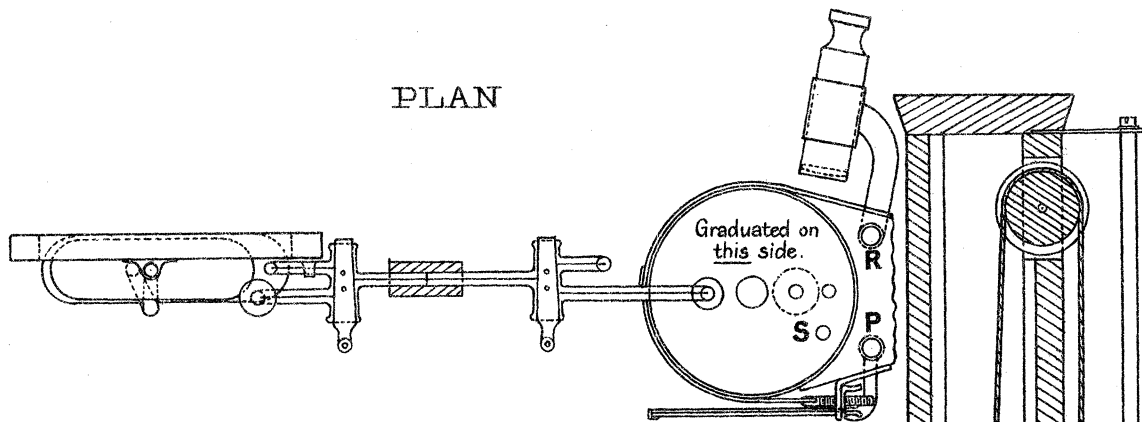Aqueous vapour 13,972·6 cub. centims. at 0° C. and 760 millims.

RECONCILIATION.

	C.	O.	H.	N.
	grammes	grammes	grammes	grammes
Found by analysis	25·55	54·12	3·19	11·54
Originally in R. R.	26·24	53·68	2·97	11·10
Differences	– 0·69	+ 0·44	+0·22	+ 0·44

Experiment 1346.—Fired in explosion vessel Q, 95·94 grammes of Rottweil R. R. Density of charge 0·30.

Pressure 20·54 tons per sq. inch (3131·0 atmospheres).

Permanent gases 70,802·3 cub. centims. at 0° C. and 760 millims.

Aqueous vapour 13,834·3 cub. centims. at 0° C. and 760 millims.

RECONCILIATION.

	C.	O.	H.	N.
	grammes	grammes	grammes	grammes
Found by analysis	26·43	56·14	3·32	12·00
Originally in R. R.	27·16	56·16	3·07	11·50
Differences	− 0·73	− 0·02	+ 0·25	+ 0·50

Experiment 1401.—Fired in explosion vessel Q, 127·92 grammes of Rottweil R. R. Density of charge 0·40.

Pressure 34·9 tons per sq. inch (5320·0 atmospheres).

Permanent gases 88,689·0 cub. centims. at 0° C. and 760 millims.

Aqueous vapour 18,946·1 cub. centims. at 0° C. and 760 millims.

RECONCILIATION.

	C.	O.	H.	N.
	grammes	grammes	grammes	grammes
Found by analysis	34·57	74·62	4·38	14·83
Originally in R. R.	35·85	73·33	4·06	15·16
Differences	− 1·28	+ 1·29	+0·32	− 0·33

Experiment 1402.—Fired in explosion vessel R, 144·54 grammes of Rottweil R. R. Density of charge 0·45.

Pressure 40·5 tons per sq. inch (6173·6 atmospheres).

Permanent gases 98,819·4 cub. centims. at 0° C. and 760 millims.

Aqueous vapour 19,568·1 cub. centims. at 0° C. and 760 millims.

RECONCILATION.

	C.	O.	H.	N.
	grammes	grammes	grammes	grammes
Found by analysis	39·29	83·47	4·86	16·61
Originally in R. R.	40·27	82·38	4·56	17·03
Differences	− 0·98	+ 1·09	+ 0·30	− 0·42

Differential Thermometer.

Thermometer.

Circulator.

Firing Wire.

To Battery.

Handle.

Circulator.

Distilled water.

Water.

Platinum Wire Bridge.

Gun cotton.

Explosion Vessel.

All surfaces electro-plated except that of the outer vessel.

Stays.

PLAN

Graduated on this side.

ELEVATION

Tachometer

Lever for changing speed.

Fast Speed.

Slow Speed.

Revolving Drum.

Diagram

Carrier for Pen.

Motor

Connection to Pen.

Pressure Indicator

Vernier

a

Firing Wires.

f

To Chronoscope.

Chronometer

Explosion Vessel.

Chronoscope Battery.

Firing Wires.

Cordite, Mk 1.

M.D.

Carbon Monoxide

Carbon Dioxide

Water

Hydrogen

Nitrogen

Marsh Gas

CO

H
H₂O

CO₂

N

CH₄

Percentages.

Density

Nitro - cellulose

Fig. 2.

Fig. 1.

·6 (·577) Cordite.

·25 Density

·2 Density

·0234

·02609

·15 Density.

·0232

·1 Density

·04207

TONS PRESSURE.

CORDITE ACTUAL DIA.R ·577   CHARGE 32 Grammes.

DENSITY ·1	PRESSURE	7·8	"	48	"
" ·15	"	12·5	"	64	"
" ·2	"	17·8	"	80	"
" ·25	"	22·4	"		

PRESSURE IN TONS PER SQ INCH.

TIME IN SECONDS.

Density ·25

·2

·15

·1

Atmospheres.

EROSION EXPERIMENTS

WITH

R.R.Tubular Powder & Cordite.

Pressure Cordite

Pressure R.R.Tubular

Erosion R.R.Tubular

Erosion Cordite

DENSITY

Pressure in Tons & Erosion in C.C.

EROSION EXPERIMENTS

WITH

R.R.Tubular Powder & Cordite.