

parts of the corona in this way. All the photographs show a bright continuous spectrum from the inner corona.

Some of the plates taken out of totality show numerous bright lines at the cusps of the crescent of the sun then visible, chief among them being the lines of hydrogen and the H and K lines of calcium; others, farther removed from the second and third contacts, show only the Fraunhofer lines.

III. "Researches on Modern Explosives.—Preliminary Communication." By WILLIAM MACNAB, F.I.C., F.C.S., and E. RISTORI, Ass. M. Inst. C.E., F.R.A.S. Communicated by Professor RAMSAY, F.R.S. Received February 28, 1894.

During the last two years we have carried out a long series of experiments with explosive compounds for the purpose of studying chemical reactions at high temperatures and pressures, and of elucidating certain thermal constants relating chiefly to the specific heat of gases under such conditions.

For these experiments we have principally used nitro-glycerin, nitro-cellulose, and several combinations of these two bodies which are used as smokeless gunpowders, for the reason that such modern explosives offer the advantage of not only presenting comparatively simple chemical reactions, owing to the absence of solid residue, but also of enabling considerable variations to be made in their composition so as to vary the proportions of the elements reacting.

We also expected that the results which we obtained would make a small contribution to the knowledge of explosives in general, following up the lines indicated by the published work of Noble and Abel, Berthelot, Sarrau, Vieille, and others.

In this preliminary communication we propose chiefly to indicate the results obtained in the measurement of the heat evolved by explosion, and of the quantity and composition of the gases produced by this metamorphosis.

We have also made considerable progress towards the determination of the actual temperature of explosion, and we have succeeded in recording these high temperatures by photographic means, but, as this work is not yet completed, we shall not further refer to it in this paper, but we hope it will make the subject of another communication at an early date.

These modern explosives, and especially the smokeless powders, have assumed of late such importance that it may be of general interest to give here a brief sketch of their development.

About thirty years ago experiments were made in Austria with the

object of using gun-cotton for the charges of rifle ammunition, but no success was obtained, and the matter dropped.

Other explosives, consisting principally of nitro-lignin or nitro-cellulose, not gelatinised, and mixed with nitrates or other substances, were afterwards invented and adopted for sporting guns successfully, and have been largely sold in the market under different well-known names. These explosives, however, were not found suitable for the charges of rifles and guns.

Further development in the science of artillery, and a better knowledge of the action of explosives, encouraged further researches for the production of new propelling agents for rifles and guns, and these researches have been so far successful that in a few years several new powders have been produced, each one of which is far superior to black gunpowder.

The new explosives now in use contain nitro-cellulose as one of their principal elements; some of them contain also nitro-glycerin in more or less proportion; the nitro-cellulose, by solution in nitro-glycerin, acetone, or other suitable solvent, is gelatinised, and by mechanical means the explosive compound is compressed and squirted into cords, or rolled into sheets, and then cut into strips or grains of suitable size for the different firearms.

The great secret of all these modern explosives seems to be that by the above means they are made into a solid substance, thus avoiding any porosity, and it appears probable that by doing so even the most powerful explosive can be mastered, so that, burning regularly from the surface, the rate of combustion can be controlled so as to avoid detonation.

This constitutes the most striking feature of the modern smokeless gunpowders, especially of those containing nitro-glycerin. If certain sized cubes, strips or cords of such powders are fired in a certain gun, and the length of this gun does not allow of sufficient time during the travel of the shot, for the explosive to be entirely consumed, the unburnt residue of the charge will be found to be of the same shape, whether cubes, strips or cords, only reduced in size; thus proving the most perfect surface combustion of these explosives.

It is thus possible to determine accurately what quantity of explosive, and what surface of combustion for the same, will be required, in order to obtain certain results in a certain gun, thus avoiding waste of powder.

This property of modern smokeless powder was illustrated on the occasion of a disastrous fire which occurred in May, 1890, at the factory of Avigliana, Italy, where large quantities of the explosive called ballistite were manufactured for the Government. In one building twelve tons of this explosive were collected, and various operations of manufacture were performed. By accident some of it

took fire, and the whole quantity was burnt in a few seconds. Though this powder was made of such powerful explosives as nitro-glycerin and nitro-cellulose, and though the amount was so large that, had it been black powder, it would have caused destruction for many miles around, still there was no explosion of any kind; none of the machinery was in any way damaged, and the wood was barely charred.

The explosives used in these experiments can be divided into three classes:—

1. Those consisting of nitro-lignin or nitro-cellulose (not gelatinised), mixed, or impregnated with a suitable nitrate, and mixed with colouring matters and some other substances for the purpose of retarding the rate of combustion. We have taken as samples of this class the EC and the SS powders now commonly used in sporting guns (the EC consisting principally of nitro-cellulose mixed with barium nitrate and a small proportion of camphor, the SS powder consisting of nitro-lignin mixed with barium nitrate and nitro-benzene).

2. Those consisting of purified nitro-lignin or nitro-cellulose gelatinised by a suitable process, and with or without the addition of nitro-benzene or other suitable nitrates.

As sample of this class we have taken the BN powder manufactured by the French Government, and also the Rifleite and the Troisdorf powder, which are now commonly used for small arms ammunition. (The BN consists mainly of gelatinised nitro-cellulose; the Troisdorf also consists of gelatinised nitro-cellulose, but is coated with graphite. Rifleite is also made with gelatinised nitro-cellulose, with the addition, however, of a certain proportion of nitro-benzene).

3. Those consisting of nitro-cellulose combined with nitro-glycerin, with the addition of aniline, camphor, vaseline, or other kindred substances. To this class belong cordite and ballistite.

Cordite contains 58 per cent. of nitro-glycerin, 37 per cent. of gun-cotton, and 5 per cent. of vaseline.

Ballistite of Italian manufacture contains equal parts of nitro-cellulose and nitro-glycerin, with the addition of $\frac{1}{2}$ per cent. of aniline.

Ballistite of German manufacture contains a slightly higher percentage of nitro-cellulose, and is coated with graphite.

Besides, for the purpose of these experiments, a series of samples of ballistite were specially made containing nitro-glycerin and nitro-cellulose in various proportions.

The experiments were carried out in two closed vessels of different dimensions and construction—a large one capable of standing high pressures, and a small one for calorimetric work.

The large one consists of a steel cylinder of great thickness, closed at both ends by conical screw-plugs. One plug is provided with a crusher-gauge of the well-known pattern by which the compression of a small cylinder of copper serves to measure the pressure developed. The other plug is provided with an insulated conical core, by means of which an electric current can be passed for the purpose of firing the charge. A small hole on the side of the cylinder, bushed with iridium-platinum, and closed by a coned screw-plug, serves to control the escape of the gases produced by the explosion.

The capacity of the chamber was carefully measured, and was found to be 247·6 c.c.

The small vessel is of the same pattern as used by Berthelot, and was made by Golaz, of Paris. It has given great satisfaction, and is in excellent order, although it has been used for more than two hundred explosions.

This bomb, which is made of mild steel and is cylindrical in shape, consists essentially of three parts—a bowl, a conical lid which is accurately ground into the bowl, and a tightening cap which screws on to the bowl over the lid.

There is a small hole in the lid provided with a delivery tube, which can be opened and closed by means of a finely-threaded conical plug. There is also an insulated platinum cone inserted from underneath in the lid, which admits of the charge in the bomb being fired by a platinum wire heated to redness by electricity.

From the lid depend platinum supports which carry a platinum capsule, in which the explosive is placed and suspended in the middle of the chamber.

The capacity of this bomb is 488 c.c., and the total weight, including a small stand, when ready for immersion in the calorimeter, is 5633·28 grams.

The calorimeter is made of thin sheet brass, and a helicoidal stirrer of the same metal (Berthelot's pattern), driven by a small electromotor during the experiment, serves to thoroughly mix the water.

The calorimeter stood in the centre of an annular water-jacket covered with felt. The quantity of water used in the calorimeter each time was 2,500 grams, and the equivalent in water of the bomb, stirrer, and calorimeter, due allowance having been made for the different specific heats of the different metals, is 623·4 grams.

The different thermometers employed were specially made by Casella, capable of being read to 0·005 of a degree centigrade, and the weights of their stems, bulbs, and mercury were known.

Various experiments were made in the large vessel, especially for the purpose of determining the pressure of the gases under different densities of charge.

These trials were carried out in a field, the bomb being lowered into a hole in the ground before firing.

Various difficulties were encountered, and in one experiment considerable damage was done by the heated gases effecting their escape at the moment of explosion, and "washing away" part of the thread of one of the screw plugs.

With a density of loading of $\Delta = 0.1$, *i.e.*, with a charge of 24.76 grams, the average of the pressures measured was 6.3 tons per square inch; with density $\Delta = 0.2$ the pressure rose to 15 tons, and with $\Delta = 0.3$ the pressure increased to 25 tons. These results are very similar to those published by Sir A. Noble, F.R.S.

With the small bomb were ascertained the amount of heat generated by the explosion, the volume and composition of the permanent gases resulting, and the quantity of aqueous vapour produced.

As most of the explosives contained no mineral matter beyond a trifling percentage of "ash," it has been possible to analyse them in this way, the products of explosion when calculated from the analysis and volume of permanent gas and aqueous vapour agreeing closely with the weight of matter in the bomb before firing.

A few of the explosives left a carbonaceous or mineral residue; but these will be specially noticed further on in connexion with the tables of the results.

The heat evolved was measured by placing the bomb containing the charge of explosive in the calorimeter containing 2500 grams of water, and it was arranged that the temperature of the air, the water jacket, and the calorimeter closely approximated each other. The stirrer was set in motion, and the thermometer in the calorimeter was read with a kathetometer. Observations of the temperatures were made every minute for the five minutes preceding the firing of the charge, and continued at intervals of a minute until the maximum was reached, and for five minutes longer. The correction for loss of heat due to radiation of heat during the experiments amounted in general to about 0.01 of a degree. The increase in temperature varied from about 1° to $2\frac{1}{2}^{\circ}$ C. according to the charge and explosive used.

The gas generated by the explosion was passed through weighed drying tubes connected with the valve on the lid of the vessel, and then collected and measured in a calibrated glass cylinder over mercury. The reading of the barometer and thermometer was noted, and the volume reduced to 0° C. and 760 mm.

The water was determined by immersing the bomb in a vessel containing boiling water. A three-way glass stop-cock intervened between the valve of the bomb and the drying tubes, and the other end of the drying apparatus was connected with a water vacuum pump.

The other branch of the three-way tap was connected with a separate drying apparatus. When the water surrounding the bomb was boiling, by starting the vacuum pump the steam and water were drawn into the absorbing apparatus; after a good vacuum had been made in the bomb the three-way tap was turned so that dry air rushed in, then connexion was made with the drying apparatus, the bomb again exhausted, and so on, alternately, until (as experience showed) all the water had been removed from the bomb and collected in the drying tubes, which were then weighed. The weights of water thus obtained were calculated for comparison into volumes of H_2O gas at $0^\circ C.$ and 760 mm.

The analyses of gas were carried out in duplicate in Dittmar's apparatus as improved by Lennox.

In most of the experiments the bomb, previous to firing, was exhausted, and the amount of residual pressure, varying from 24 to 40 mm., noted on closing it. The amount of air corresponding to these pressures left in the bomb has the effect of increasing the heat generated by a small quantity amounting to 5 to 7 calories. This quantity being within the limits of error of the calorimetric observation no correction was made for the same, but the quantity of residual air was taken into account when comparing the weights of the products found with the weight of the explosive used. Thus in Tables I and II the volumes of gas of the given composition and of aqueous vapour were obtained from the given weight of explosive increased by the weight of the air corresponding to the vacuum indicated.

When firing in an exhausted bomb it was found necessary to have the explosive surrounding the firing wire in comparatively small pieces in order to ensure ignition of the whole charge.

Table I gives the principal results obtained with the several gunpowders above mentioned, Tables II and III give the results obtained with samples of ballistite made with different proportions of the component parts, Table IV indicates the effect of firing different weights of the same explosive in a closed vessel from which the air has *not* been exhausted, and Table V gives the original elementary composition of several explosives compared with the products of combustion, both being represented as weights.

With the exception of the results given in Table IV, all the others were obtained from the firing of 4 grams of the explosive.

In Tables I and II we have expressed the results of firing some powders now in use as well as certain specially prepared powders, so as to show the quantity of heat and the volumes and analyses of the gases produced, and have in the column headed "Coefficient of potential energy," given figures which serve as a measure of comparison of the power of the several explosives. These figures are

Table I.—Indicating the Quantity of Heat, also the Volume and Analysis of the Gas developed per gram with different Sporting and Military Smokeless Powders now in use.

Name of explosive.	Calories per gram.	Permanent gases.	Aqueous vapour.	Total volume of gas calculated at 0° and 760 mm.	Per cent. composition of permanent gases.					Coefficient of potential energy.
					CO ₂ .	CO.	CH ₄ .	H.	N	
EC powder	800	C.c. per gram. 420	C.c. per gram. 154	C.c. per gram. 574	22·9	40·6	0·5	15·5	20·5	459
SS sporting powder	799	584	150	734	18·2	45·4	0·7	20·0	15·7	586
Troisdorf, German.....	943	700	195	895	18·7	47·9	0·8	17·4	15·2	844
Riflete, English.....	864	766	159	925	14·2	50·1	0·3	20·5	14·9	799
BN, French.....	833	733	168	906	13·2	53·1	0·7	19·4	13·6	755
Cordite, English manufacture.....	1253	647	235	882	24·9	40·3	0·7	14·8	19·3	1105
Ballistite, German manufacture.....	1291	591	231	822	33·1	35·4	0·5	10·1	20·9	1061
Ballistite, Italian and Spanish manufacture..	1317	531	245	826	35·9	32·6	0·3	9·0	22·2	1088

the products of the number of calories by the volumes of gas, the last three figures being suppressed in order to simplify the results.

In the case of EC and SS a certain amount of mineral residue was left, but this was not determined.

Troisdorf leaves a slight, and Rifleite and BN a considerable, carbonaceous residue, part of it adhering so tenaciously to the bomb that an exact determination was not made.

In the other experiments recorded in Tables I and II the degree of accuracy of the results may be gauged by the fact that the average weight of the products of explosion, calculated from the results found, amounts to 99·7 per cent. of the weight of the explosive fired, the extreme limits being 100·5 and 98·9 per cent.

In Table II the comparison of the pairs of results from explosives made with lower and more highly nitrated nitro-cellulose shows that the use of the highly nitrated cellulose increases the quantity of heat developed, and diminishes the volume of gas. The composition

Table III.—Showing the Heat developed by Explosives containing Nitro-glycerin and Nitro-cellulose in different proportions.

Composition of explosives.			Calories per gram.
Nitro-cellulose (N = 13·3 per cent.)	Nitro-glycerin.		
100 per cent. (dry pulp)	0	1061	
100 " " (gelatinised)	0	922	
90 " "	10 per cent.	1044	
80 " "	20 " "	1159	
70 " "	30 " "	1267	
60 " "	40 " "	1347	
50 " "	50 " "	1410	
40 " "	60 " "	1467	
0 " "	100 " "	1652	
Nitro-cellulose (N = 12·24 per cent.)	Nitro-glycerin.		
80 per cent.	20 per cent.	1062	
60 " "	40 " "	1288	
50 " "	50 " "	1349	
40 " "	60 " "	1405	
Nitro-cellulose (N = 13·3 per cent.)	Vaseline.	Nitro-glycerin.	
55 per cent.	5 per cent.	40 per cent.	
35 " "	5 " "	60 " "	1134
			1280

of the permanent gases is also altered, as might be expected, there being an increase in carbonic acid and decrease in carbonic oxide and hydrogen.

The similarity in the volumes of gas produced and the composition of the permanent gases in the case of experiments F and G is worthy of note when the great difference in the original component ingredients of the explosives is borne in mind.

Table III shows clearly the increase of heat due to increased percentage of nitro-glycerin, as well as the difference of heat evolved from explosives containing nitro-cellulose of different degrees of nitration.

The diminution in quantity of heat (about 200 calories) which the replacement of 5 per cent. of nitro-cellulose by vaseline makes is also very striking.

Table IV.—Showing the Heat developed and the Analysis of the Permanent Gas produced in a closed Vessel from which the Air has not been exhausted—the Explosive being in every case Ballistite of Italian Manufacture.

Charge.	Calories per gram.	Analysis of the permanent gas.			
		CO ₂ .	CO.	H.	N.
2 grams.....	1587	37·0	17·6	3·2	42·2
3 „	1485	36·4	22·0	4·6	37·0
4 „	1446	36·2	24·6	6·1	33·1
5 „	1415	36·2	26·0	7·2	30·6
6 „	1380	36·3	27·0	7·9	28·6

Traces of CH₄ were found, but in this series of experiments the quantity of this gas was not determined.

Table IV shows the part played by the oxygen of the air in the bomb; when a smaller proportion of explosive in comparison with the air is present the combustion is more complete, and the heat evolved is greater, and the composition of the gases is correspondingly modified.

In Table V the elementary percentage composition of some of the explosives, along with the percentage composition of the products of explosion by weight, is given.

The composition of the samples has been calculated from the “bomb” analyses; as an example, one of the explosives and its decomposition may be represented approximately by the following equation.

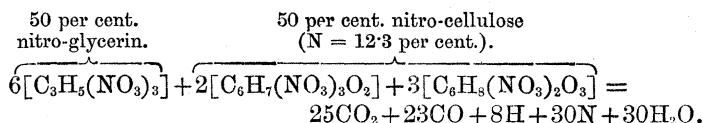
We have assumed the nitro-cellulose to consist of a mixture of di-

Table V.—Showing the original Composition and Metamorphosis of Nitro-cellulose, Nitro-glycerin, and of several Gunpowders made by Combinations of these two Explosives.

Nature and description of explosive.	Per cent. composition by weight.				Per cent. products of combustion by weight.						
	Carbon, C.	Oxygen, O.	Hydrogen, H.	Nitrogen, N.	Carbonic acid, CO ₂ .	Carbonic oxide, CO.	Marsh gas, CH ₄ .	Oxygen, O.	Hydrogen, H.	Nitrogen, N.	Water, H ₂ O.
A. Nitro-glycerin	15.7	63.0	2.3	18.8	57.6	—	—	2.7	—	18.8	20.7
B. Nitro-cellulose (nitrogen = 13.3)	24.58	57.68	2.73	13.6	29.27	38.52	0.24	—	0.86	13.6	16.30
C. { 50 per cent. nitro-cellulose (N = 12.24 per cent.) 50 per cent. nitro-glycerin	21.15	60.67	2.67	15.58	41.0	23.1	0.08	—	0.4	15.58	20.01
D. { 50 per cent. nitro-cellulose (N = 13.30 per cent.) 50 per cent. nitro-glycerin	20.47	61.23	2.49	16.35	45.3	19.0	0.00	—	0.3	16.35	19.90
E. { 80 per cent. nitro-cellulose (N = 12.24 per cent.) 20 per cent. nitro-glycerin	24.37	58.98	2.98	14.0	28.9	38.4	0.05	—	1.0	14.0	18.2
F. { 80 per cent. nitro-cellulose (N = 13.30 per cent.) 20 per cent. nitro-glycerin	23.11	58.98	2.71	15.84	33.4	32.6	0.04	—	0.7	15.84	18.2
G. { 35 per cent. nitro-cellulose (N = 13.30 per cent.) 5 per cent. vaseline	22.2	59.0	2.88	15.46	33.0	31.3	0.2	—	0.7	15.46	19.0
H. { 60 per cent. nitro-glycerin Cordite, English manufacture	22.91	57.72	2.95	15.19	31.76	32.68	0.32	—	0.86	15.19	18.08
K. Ballistite, Italian and Spanish manufacture	21.47	60.83	2.68	15.80	41.11	23.76	0.12	—	0.47	15.8	19.69

and tri-nitro-cellulose in proportion corresponding to the nitrogen as found by analysis.

The equation for Experiment C may be taken as follows :—



The composition of this explosive, calculated from the foregoing formula and found by analysis, is as follows :—

	Formula.	Analysis.
C.....	21.2	21.15
O	60.8	60.67
H	2.5	2.67
N	15.5	15.58
	<hr/> 100.0	<hr/> 100.07

These are some of the principal features noticeable in a preliminary survey of these experiments. We are continuing our investigations on the lines indicated in the paper, and are especially endeavouring to measure the actual temperature of explosion under varying conditions, and it is hoped that the results obtained will throw some light on the chemical and physical properties of many gases at high temperatures and under considerable pressures, and, at the same time, be useful in the practical application of explosives.

IV. "On the Leicester Earthquake of August 4, 1893." By CHARLES DAVISON, M.A., Mathematical Master at King Edward's High School, Birmingham. Communicated by Professor J. H. POYNTING, F.R.S. Received February 28, 1894.

(Abstract.)

On August 4, 1893, at 6.41 P.M., an earthquake of intensity nearly equal to 6 (according to the Rossi-Forel scale) was felt over the whole of Leicestershire and Rutland and in parts of all the adjoining counties. The disturbed area was 58 miles long, 46 miles broad, and contained an area of about 2066 square miles. The direction of the longer axis (about W. 40° N. and E. 40° S.) and the relative position of the isoseismal lines show that the originating fault, if the earthquake were due to fault-slipping, must run in about the direction indicated, passing between Woodhouse Eaves and Markfield, and heading