VIII. *Researches on Explosives.* No. II.—*Fired Gunpowder.*

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Contents.

During the course of the experiments that we have undertaken in extending our researches on explosives to the investigation of the action and results of fired gun-cotton, we have had occasion to examine some points connected with the subject of our former memoir on "Fired Gunpowder;" and as the attention which the researches described in that memoir have received, especially on the Continent, is an evidence both of the theoretical and practical importance of our subject, we propose, prior to laying before the Society our researches on gun-cotton, to discuss a few points of considerable interest which have arisen out of our former investigations, and to give the results of some further experiments on gunpowder.

The Academy of Sciences of France having done us the honour to appoint a Commission to report on our researches, there have appeared in the 'Comptes Rendus' a joint report* by General MORIN and M. BERTHELOT, and two† separate memoirs on certain chemical points by the latter savant.

The high appreciation of our labours shown by the Academy has induced us to pay special attention to one or two points mentioned by the distinguished reporters as being open to discussion; we will now proceed to consider them, and to detail some further experiments calculated to throw light upon the different questions raised.

The principal points to which General MORIN and M. BERTHELOT draw attention are—

1. Potassium hyposulphite has been found as one of the products of combustion of gunpowder by every recent investigator. But the question arises, Is this product either wholly or in part primary? Or is it to be considered as secondary, formed from the primary products during the rapid loss of heat to which they are exposed? Or is it, finally, to be considered only as formed from the sulphide by the absorption of oxygen, during the processes of removal from the cylinder and of analysis, and therefore to be regarded as an accidental product?

2. In the memoir in question we stated 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."

M. BERTHELOT, however, in a memoir upon the explosion of powder, based on our results, proposes to represent these results by a system of simultaneous equations expressing the chemical metamorphosis undergone by powder, at least as far as regards its fundamental products.

3. In the joint report of General MORIN and M. BERTHELOT, and in the separate memoir above referred to of M. BERTHELOT, special attention is called to the heat disengaged by the explosion, and our determination, presented, as the reporters point out, with some reserve, is considered to be too low, partly because the apparatus used did not admit of extreme delicacy, and partly because higher determinations have been made by M. TROMENEC and MM. ROUX and SARRAU.

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* 'Comptes Rendus,' tom. lxxxii., p. 487.

† Idem., pp. 400 and 469.

We now proceed to the discussion at length of these points, prefacing our remarks by Tables I. and II. hereto annexed.

The former of these tables, in addition to giving the results of one or two analyses which had not been completed when our first memoir was published (we have not considered it necessary to repeat the portions of this table already published), shows the mean percentage composition, by volume, of the gases, and the mean percentage composition, by weight, of the solid residues for each of the three principal powders examined by us. It also shows the highest and lowest proportions in which, with each powder, any particular product occurs, and gives the results obtained from the examination of the products of combustion of four descriptions of powder differing in many respects from the powders which formed the main subject of our memoir.

Table II. contains the complete results of all our analyses; it shows the proportion by weight of each solid and gaseous product, and includes also the amount of water pre-existent in the various specimens of powder operated on.

TABLE I.*—Showing the mean analytical results obtained from an examination of the solid and gaseous products of decomposition of pebble, R. L. G., and F. G. powders; showing also the same particulars with respect to four other powders.

Nature of powder.	Mean density of products of combustion.	Percentage composition by volume of the gas.							Percentage composition by weight of the solid residue.									
		Carbonic anhydride.	Carbonic oxide.	Nitrogen.	Sulphydric acid.	Marsh gas.	Hydrogen.	Oxygen.	Potassium carbonate.	Potassium sulphate.	Potassium hyposulphite.	Potassium monosulphide.	Potassium sulphocyanate.	Potassium nitrate.	Potassium oxide.	Ammonium sesqui-carbonate.	Sulphur.	Charcoal.
Pebble, W. A.	Means	48·92	13·70	32·13	2·60	0·31	2·34	..	57·19	12·47	13·89	10·25	0·27	0·23	..	0·10	5·45	0·15
	Highest	51·75	16·09	32·75	4·23	0·68	3·50	..	64·20	15·02	32·18	19·12	0·57	0·48	..	0·17	8·45	1·35†
	Lowest	44·78	10·87	31·31	1·70	..	1·67	..	50·20	9·13	3·71	2·23	0·06	..	..	0·06	0·61	Trace.
R. L. G., W. A.	Means	49·29	12·47	32·91	2·65	0·43	2·19	0·06	59·06	14·59	13·20	6·27	0·22	0·26	..	0·07	6·26	0·07
	Highest	52·65	17·04	35·60	4·29	0·84	3·01	0·57	66·51	24·22	25·33	9·92	0·49	0·56	..	0·18	12·03	0·71
	Lowest	46·29	8·98	30·29	1·56	..	1·27	..	48·68	4·64	3·08	2·02	0·05	..	..	0·04	1·25	Trace.
F. G., W. A.	Means	50·63	10·46	33·20	2·48	0·19	2·96	0·08	48·32	21·11	24·79	2·41	0·12	0·16	1·29	0·05	1·75	..
	Highest	53·34	16·25	34·64	3·76	0·50	4·13	0·28	59·39	24·22	34·61	5·12	0·25	0·26	5·39	0·15	5·72	..
	Lowest	44·76	7·71	32·22	2·00	..	2·04	..	41·88	17·86	5·30	..	0·02	0·08	..	0·01	0·09	..
96. R. L. G., W. A.	60 per cent.	46·29	14·52	32·40	4·29	0·36	2·14	..	65·27	10·71	6·89	7·65	0·28	0·45	..	0·09	8·66	..
78. R. F. G., W. A.	70 „	52·40	8·86	34·51	1·60	0·12	2·51	..	58·94	21·89	8·15	4·22	0·04	0·06	..	0·06	6·65	Trace.
79. Spanish spherical	70 „	53·34	4·62	37·80	2·74	..	1·29	0·21	34·97	47·62	7·60	3·17	0·04	0·93	..	0·04	5·63	..
196. CURTIS and HARVEY'S No. 6	30 „	50·22	7·52	34·46	2·08	2·46	3·26	..	58·51	21·43	3·93	10·02	..	0·29	..	0·09	5·73	..
194. Mining powder	30 „	32·15	33·75	19·03	7·10	2·73	5·24	..	40·78	0·58	5·84	33·20	2·92	0·09	..	1·76	12·93	2·00

* See Table XII.

† Not estimated—insoluble residue chiefly iron pyrites.

TABLE II.*—Composition by weight of the products of combustion of 1 gramme of fired gunpowder of the undermentioned natures, and of various gravimetric densities.

No. of experiments.	Nature of powder.	Mean density of products of combustion.	Proportions by weight of gaseous products.							Proportions by weight of the solid residue.										Water.	Proportion by weight of total gaseous products.	Proportion by weight of total solid products.	Water.
			Carbonic anhydride.	Carbonic oxide.	Nitrogen.	Sulphydric acid.	Marsh gas.	Hydrogen.	Oxygen.	Potassium carbonate.	Potassium sulphate.	Potassium hyposulphite.	Potassium monosulphide.	Potassium sulphocyanate.	Potassium nitrate.	Potassium oxide.	Ammonium sesqui-carbonate.	Sulphur.	Charcoal.				
8	Pebble, W. A.. . .	10	·2553	·0514	·1140	·0133	..	·0007	..	·3084	·0835	·1152	·0412	·0005	·0027	..	·0009	·0034	..	·0095	·4347	·5558	·0095
7		20	·2494	·0570	·1108	·0182	..	·0009	..	·3186	·0760	·0206	·1001	·0003	..	..	·0005	·0381	..	·0095	·4363	·5542	·0095
9		30	·2595	·0545	·1113	·0124	..	·0007	..	·3282	·0696	·0239	·0911	·0012	·0002	..	·0007	·0372	..	·0095	·4384	·5521	·0095
12		40	·2624	·0471	·1085	·0069	·0006	·0006	..	·3115	·0745	·0794	·0548	·0014	·0005	·0077	·0004	·0342	..	·0095	·4261	5644	·0095
14		50	·2743	·0469	·1128	·0083	·0012	·0005	..	·3069	·0652	·0335	·1045	·0013	·0011	..	·0003	·0337	..	·0095	·4440	·5565	·0095
37		60	·2654	·0470	·1087	·0093	·0011	·0005	..	·3213	·0752	·0556	·0641	·0019	·0017	..	·0003	·0384	..	·0095	·4320	·5585	·0095
38		70	·2604	·0415	·1065	·0128	·0007	·0005	..	·2852	·0726	·1827	·0127	·0022	·0014	..	·0003	·0110	..	·0095	·4224	·5681	·0095
43		80	·2690	·0396	·1084	·0080	·0006	·0004	..	·3322	·0584	·1167	·0220	·0026	·0018	..	·0005	·0303	..	·0095	·4260	·5645	·0095
77		90	·2684	·0359	·1080	·0085	·0013	·0005	..	·3645	·0518	·0754	·0218	·0032	·0025	..	·0007	·0480	..	·0095	·4226	·5679	·0095
		Means	·2627	·0468	·1099	·0109	·0006	·0006	..	·3196	·0696	·0781	·0569	·0016	·0013	·0009	·0005	·0306	..	·0095	·4314	·5601	·0095
		Highest	·2743	·0570	·1140	·0182	·0013	·0009	..	·3645	·0835	·1827	·1045	·0032	·0027	·0077	·0009	·0480	..	·0095	·4440	·5681	·0095
		Lowest	·2494	·0359	·1065	·0069	..	·0004	..	·2852	·0518	·0206	·0127	·0003	·0002	..	·0003	·0034	..	·0095	·4224	·5521	·0095
1	R. L. G., W. A. . . .	10	·2569	·0300	·1188	·0164	·0006	·0005	..	·2972	·1160	·1154	·0228	..	·0032	..	·0003	·0041	·0072	·0106	·4232	·5662	·0106
3		20	·2477	·0389	·1189	·0148	·0001	·0006	·0022	·3094	·1364	·0326	·0541	·0003	·0007	..	·0004	·0323	·0001	·0106	·4232	·5662	·0106
4		30	·2582	·0386	·1096	·0126	..	·0007	..	·2984	·1380	·0732	·0334	·0003	·0002	..	·0002	·0260	..	·0106	·4197	·5697	·0106
11		40	·2595	·0356	·1125	·0077	·0005	·0006	..	·2789	·1310	·1379	·0116	·0009	·0007	..	·0002	·0118	..	·0106	·4164	·5730	·0106
70		50	·2494	·0558	·1011	·0065	·0016	·0007	..	·3482	·0266	·1455	·0204	·0017	·0029	..	·0006	·0284	..	·0106	·4151	·5743	·0106
39		60	·2648	·0467	·1065	·0066	·0007	·0005	..	·3597	·0619	·0365	·0559	·0015	..	..	·0006	·0475	..	·0106	·4258	·5636	·0106
96		60	·2457	·0490	·1090	·0176	·0007	·0005	..	·3702	·0608	·0392	·0434	·0016	·0026	..	..	·0491	..	·0106	·4225	·5669	·0106
41		70	·2576	·0441	·1053	·0114	·0011	·0004	..	·3435	·0600	·1059	·0219	·0028	·0024	..	·0001	·0329	..	·0106	·4199	·5695	·0106
44		80	·2672	·0401	·1060	·0062	·0014	·0004	..	·3777	·0501	·0175	·0514	·0014	·0010	..	·0006	·0684	..	·0106	·4213	·5681	·0106
68		90	·2720	·0352	·1074	·0076	·0015	·0003	..	·3715	·0482	·0486	·0409	·0021	·0011	..	·0009	·0521	..	·0106	·4240	·5654	·0106
		Means	·2580	·0414	·1095	·0106	·0008	·0005	·0002	·3355	·0829	·0752	·0356	·0013	·0015	..	·0004	·0353	·0007	·0106	·4211	·5683	·0106
		Highest	·2720	·0558	·1189	·0176	·0016	·0007	·0022	·3777	·1380	·1455	·0559	·0028	·0032	..	·0009	·0684	·0072	·0106	·4258	·5743	·0106
		Lowest	·2457	·0300	·1011	·0062	..	·0003	..	·2789	·0266	·0175	·0116	..	..	..	..	·0041	..	·0106	·4151	·5636	·0106
16	F. G., W. A.	10	·2423	·0561	·1122	·0095	·0004	·0010	·0006	·2772	·1005	·1338	·0193	..	·0011	·0308	·0004	..	..	·0148	·4221	·5631	·0148
17		20	·2475	·0410	·1074	·0153	..	·0010	..	·3401	·1388	·0304	·0294	·0001	·0005	..	·0009	·0328	..	·0148	·4122	·5730	·0148
18		30	·2586	·0370	·1050	·0088	..	·0008	·0010	·2645	·1302	·1583	·0161	·0004	·0006	..	·0001	·0038	..	·0148	·4112	·5740	·0148
19		40	·2639	·0334	·1055	·0079	..	·0008	..	·2576	·1250	·1640	·0193	·0004	·0005	..	·0002	·0067	..	·0148	·4115	·5737	·0148
75		50	·2611	·0338	·1080	·0087	·0005	·0007	..	·3207	·1186	·0768	·0248	·0004	·0005	..	·0005	·0301	..	·0148	·4128	·5724	·0148
40		60	·2651	·0312	·1080	·0089	·0003	·0006	..	·2391	·1269	·1822	..	·0009	·0010	·0183	·0001	·0026	..	·0148	·4141	·5711	·0148
42		70	·2678	·0253	·1100	·0080	·0009	·0005	·0006	·2461	·1202	·1836	..	·0013	·0011	·0170	·0002	·0026	..	..	·4131	·5721	·0148
47		80	·2598	·0265	·1105	·0101	·0008	·0005	·0007	·2514	·1218	·1995	..	·0014	·0015	..	·0002	·0005	..	·0148	·4089	·5763	·0148
69		90	·2698	·0247	·1088	·0116	·0003	·0005	..	·2880	·1046	·1474	·0152	·0014	·0015	..	·0002	·0112	..	..	·4157	·5695	·0148
		Means	·2596	·0343	·1084	·0099	·0003	·0007	·0003	·2762	·1207	·1418	·0138	·0007	·0009	·0074	·0003	·0100	..	·0148	·4135	·5717	·0148
		Highest	·2698	·0561	·1122	·0153	·0009	·0010	·0010	·3401	·1388	·1995	·0294	·0014	·0015	·0308	·0009	·0328	..	·0148	·4221	·5763	·0148
		Lowest	·2423	·0247	·1050	·0079	..	·0005	..	·2391	·1005	·0304	..	..	·0005	..	·0001	..	..	..	·4089	·5631	·0148
78	R. F. G., W. A. . . .	70	·2652	·0285	·1110	·0063	·0002	·0006	..	·3420	·1268	·0472	·0245	·0002	·0004	..	·0005	·0386	..	·0080	·4118	·5802	·0080
79	Spanish spherical . .	70	·2424	·0133	·1091	·0096	..	·0003	·0007	·2161	·2943	·0470	·0196	·0003	·0058	..	·0002	·0348	..	·0065	·3754	·6181	·0065
196	CURTIS & HARVEY's No. 6	30	·2576	·0245	·1124	·0082	·0046	·0008	..	·3395	·1243	·0228	·0582	..	·0017	..	·0005	·0332	..	·0117	·4081	·5802	·0117
194	Mining powder . . .	30	·2254	·1508	·0849	·0385	·0070	·0017	..	·1938	·0028	·0277	·1578	·0138	·0004	..	·0084	·0614	·0095	·0161	·5083	·4756	·0161

* See Table XIII.

A careful examination into the nature and proportions of the products furnished by the explosion of three descriptions of service gunpowder, differing but little in composition from each other, and by one and the same sample of powder under different conditions as regards pressure (or space in which the explosion took place), led us to the conclusion, which it may be as well to repeat in the precise terms used in our former memoir, namely, that "any attempt to express, even in a comparatively complicated chemical equation, the nature of the metamorphosis which a gunpowder of average composition may be considered to undergo when exploded in a confined space, would . . . . only be calculated to convey an erroneous impression as to the simplicity or the definite nature of the chemical results, and their uniformity under different conditions" (p. 85).

In giving expression in the foregoing terms to this conclusion, we certainly did not intend to convey the impression, nor do we consider that our words are at all susceptible of the interpretation, that it was impossible to put into some form of equation (as was done, for instance, by BUNSEN and SCHISCHKOFF in the case of the analytical results arrived at by them), a representation of a variety of reactions, which if *assumed* to take place simultaneously among different proportions of the powder-constituents, might express results approximating to one or other of the analytical results obtained by us, and might thus afford some approximate theoretical representation of the metamorphosis of gunpowder when fired in closed vessels.

But the very great variations in composition (of the solid portion more especially) of the products of explosion of samples of gunpowder presenting only small differences in constitution, afforded, in our opinion, most conclusive proof that the reactions which occur among the powder constituents are susceptible of very considerable variations, regarding the causes of which it appears only possible to form conjectures, and that consequently "no value whatever can be attached to any attempt to give a general chemical expression to the metamorphosis of gunpowder of normal composition."

In one of the series of interesting communications made by M. BERTHELOT to the Académie des Sciences in 1876,[*] as contributions to the "History of Explosive Agents," that chemist gives to our conclusions, as expressed in our former memoir, an interpretation which, as above pointed out, they certainly cannot be considered to bear, when he says we have stated that the variations in the proportions of the principal products of explosion are opposed "to all general chemical representation of the metamorphosis produced by the explosion," an opinion contrary, as he states, to all that is known in chemistry. Starting with the above assumption of the nature of our views, M. BERTHELOT proceeds to demonstrate that, in order to account for the formation of the *chief* products in some particular proportion in which potassium sulphate is so small as to allow of its being neglected, the powder-constituents must be presumed to react upon each other simultaneously, in prescribed proportions, according to *three*, or, if the sulphate amount to 12 or 14 per cent., according to *four* out of *five* different

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[*] 'Comptes Rendus,' tom. lxxxii., p. 400.

theoretical reactions, which, if assumed to occur simultaneously, in variable proportion and number, M. BERTHELOT regards as satisfactorily explaining ("and definitely reducing to five simple reactions") the formation of carbon dioxide, carbon oxide, potassium sulphate, sulphide and carbonate, from a powder of what we call normal composition.*

After giving further equations which apply to the extreme results (in regard to the chief products only) assumed to be obtainable from the introduction, on the one hand, of excess of saltpetre, on the other, of excess of charcoal, into the composition of powder, M. BERTHELOT passes to what he terms the accessory products and, excluding from these potassium hyposulphite, which he deals with separately, he first gives two equations to account for the production of sulphocyanide; then two more to explain the existence of ammonium sesquicarbonate (which he believes to be formed by the action of water-vapour on potassium cyanide). The existence of sulphuretted or free hydrogen are explained by two more equations, and marsh gas is assumed to result from "the pyrogenous decomposition of the charcoal in the powder." Lastly, an equation is given to account for the possible formation of traces of hyposulphite, which BERTHELOT however regards entirely as a product formed during the collection and analytical treatment of the solid residue, but which we nevertheless believe we

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* The five simple reactions in question are thus explained:—

1. $NO_6K+S+C_3=K.S.+3CO_2+N.$
2. ,, ,, ,, $=K.C.O_3+CO.+CO_2+N+S.$
3. ,, ,, ,, $=KCO_3+1\frac{1}{2}C\,O._2+N+S+\frac{1}{2}C.$
4. ,, ,, ,, $=KSO_4+2CO.+N+C.$
5. ,, ,, ,, $=KSO_4+CO._2+N+C_2.$

When sulphate is formed in such small quantities that it may be neglected, the simultaneous reactions supposed to occur are 1, 2, and 3, by quantities of the powder proportionate to the numbers $\frac{1}{3}$, $\frac{1}{2}$, and $\frac{1}{6}$, but when the sulphate amounts to 12 or 14 per cent., the simultaneous reactions supposed to occur are Nos. 1, 3, 4, and 5, with quantities of powder corresponding to the numbers $\frac{1}{3}$, about $\frac{1}{2}$, $\frac{1}{8}$, and $\frac{1}{12}$. As there is only one single instance out of twenty-nine analyses of powder residues in which the sulphate was found to amount to as little as 4·6 per cent. of the solid products (the next lowest proportion being nearly double that amount), it can scarcely be assumed that M. BERTHELOT'S first arrangement of reactions can represent any but a most exceptional result. Again, the acceptance of his arrangement of four equations in the proportions he indicates as accounting for the formation of the chief products when the sulphate amounts to 12 or 14 per cent. of the total constituents, involves the assumption that a somewhat considerable proportion of charcoal should remain unoxidised; in fact, nearly 2·5 per cent. of carbon should be found in the residue. The detection and determination of such a constituent of powder-residue does not involve any difficulty, yet there were only three instances out of eighteen residues (in which the sulphate was considerable in amount) where the charcoal was present in estimable quantities; in two of these it was below 1 per cent., in the other it was only 0·01 per cent. In a few other residues only traces of charcoal were discovered; the larger number contained none.

These points are referred to in illustration of how imperfectly M. BERTHELOT'S not very simple arrangement of theoretical reactions correspond to the results actually obtained, even so far only as the chief products are concerned.

shall conclusively prove* to be formed in very notable quantities before the solid residue can have undergone alteration from external causes.

It will be seen from the foregoing outline of M. BERTHELOT's theoretical explanation of the chemical changes involved in the metamorphosis of gunpowder, that the simplest form of expression which he can give to the formation of the products of explosion consists in the incorporation of nine or ten distinct reactions occurring simultaneously, but in very variable proportions, which have to be supplemented by three or four other chemical equations, by which the formation, during the process of cooling, of certain products believed to be secondary, is explained. Now, although such speculations as the above are unquestionably interesting, and, it may be added, of a nature which must occur to those who desire to give some kind of definite explanation, for purposes of elementary instruction, of the chemical changes involved in the explosion of powder, we fail to see that beyond this they do more than afford the strongest confirmation of the correctness of our conclusion, that "no value whatever can be attached to any attempt to give a general chemical expression to the metamorphosis of a gunpowder of normal composition."

With regard to the *potassium hyposulphite* which is included in our statement of the composition of the solid products of explosion, we have to submit the following considerations.

In the analytical results furnished by the solid residues, as detailed in our first memoir, the hyposulphite ranged in amount from 3 to 35 per cent.; and on comparing the results of different analyses, it is observed that in most instances the proportion of monosulphide was small when the hyposulphite was large in amount, and in a few instances—all of them F. G. powder-residues—in which the proportion of the latter was very high, there was no sulphide at all.

Being fully alive to the possibility of the existence of potassium polysulphide in the solid residue giving rise to the production of some hyposulphite through the agency of atmospheric oxygen, great precautions were taken, especially in the later experiments, in collecting and preserving the residue and in submitting it to treatment for analysis, to guard against this possible source of error.

In the first place, it should be mentioned that the residue consisted in nearly all cases of fused, very hard masses, collected at the bottom of the explosion vessel, the sides of which were, moreover, generally covered with very thin films. The action of atmospheric oxygen upon the fused solid could only be superficial, but would vary in extent with the amount of surface of the residue exposed to the air during removal from the explosion apparatus or subsequent exposure. The latter was avoided as much as possible, as the residues were transferred at once, as they were detached from the surfaces of the explosion-vessel, into small bottles, in which they were carefully sealed up. It was only in one or two instances that, before opening the bottles, an

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* See note at end of this memoir.

odour of sulphuretted hydrogen, distinctly perceptible at the sealed surfaces of the mouths, indicated a slight imperfection in the sealing of the bottles.

The difficulties in the way of reducing to a minimum the exposure to air of the residues during their detachment from the explosion-vessel were, however, very much greater. We pointed out in our first memoir that in almost all cases the residues were in the form of exceedingly hard and compact masses, which had to be cut out with steel chisels, and that, although portions of the mass were detached in the form of lumps, a considerable amount of it flew off before the chisel in fine dust. The utmost care was taken to avoid exposure of the detached residues to the air, but it was of course impossible to avoid their being more or less attacked by atmospheric oxygen during the period of their collection. There is no doubt, moreover, that the residues, which differed greatly from each other in structure and in their tendency to absorb moisture and to become heated upon exposure to air, were susceptible in very variable degree to atmospheric oxidation. We, therefore, are quite prepared to admit that, of the large amount of hyposulphite found in a number of the analyses, a proportion, and in some instances possibly a large one, may have been produced by the agency of atmospheric oxygen during the removal of the residue from the apparatus; and the results of some special experiments, which we shall presently quote, appear to favour the conclusion that in those instances where no sulphide was discovered, its absence may have been ascribable to atmospheric oxidation. We regret having neglected to make any reference to this probable source of error in describing the results of our analyses, our belief being at the time that any important alteration of the residue by atmospheric action was sufficiently guarded against; at the same time, it is right we should point out that, in several instances in which the circumstances attending the manipulation of the solid residue and its consequent mechanical condition were apparently most favourable to its accidental oxidation, the proportion of hyposulphite formed was comparatively moderate in amount.

On the other hand, we cannot concur in M. BERTHELOT's view that the existence of hyposulphite among our analytical results is also ascribable in part to accidental oxidation of potassium sulphide during the analytical manipulations. These were carried out with great uniformity so far as certain preliminary operations were concerned, which consisted, firstly, in dissolving the residue in water which had been carefully boiled to expel air, and, secondly, in filtering the solution in closed vessels—both of these being rapidly completed operations. The receiving vessel contained pure ignited cupric oxide, with which, as soon as the filtering operation was completed, the solution was agitated until it became colourless.

The fact that in some of the analyses, all of which, we repeat, were uniformly conducted in regard to the above points, from 3 to 10 per cent. only of hyposulphite were found, while the proportion of monosulphide in these analyses ranged from 7 to 19 per cent. (being above 9 per cent. in eight instances), appears to afford substantial proof that accidental atmospheric oxidation during the collection and analysis of the residues is not sufficient to account for all but the very small quantities of hyposulphite which M. Berthelot considers could only have pre-existed in the residue examined by us. That chemist appears, moreover, to have overlooked the following facts given by us in our first memoir :—

1. Separate examinations (conducted precisely alike) of the upper and lower portions of some of the residues showed that considerably larger proportions of hyposulphite existed in the *upper* portions. In one case quoted by us in our first memoir, the upper portion contained 17·14 per cent. of hyposulphite, while the lower portion only contained 4·34 per cent. At the same time there was only a difference of 1·27 per cent. in the proportions of monosulphide existing in the two portions of the residue (6·03 in the upper part, and 7·3 in the lower), while there was a very great difference in the amount of free sulphur (4·88 in the upper part, and 10·09 in the lower).

2. One of the small buttons of the fired solid products, of which there was generally one found attached to the firing plug in the cylinder, was examined for sulphide and hyposulphite (it having been detached without fracture, and at once sealed up in a small tube). It contained the latter, but none of the former, while the mass of the residue of this particular experiment contained a somewhat considerable proportion of sulphide.

3. The production of high proportions of hyposulphite was but little affected by any variations in the circumstances attending the several explosions (*i.e.*, whether the spaces in which the powder was exploded were great or small), excepting that the amount was high in all three cases when the powder was exploded in the largest space. On the other hand, a great reduction in the size of grain of the gunpowder used appeared to have a great influence upon the production of hyposulphite, as when passing from a very large grain powder (pebble or R. L. G.) to a fine grain powder (F. G.).

Thus the production of hyposulphite exceeded 20 per cent. in—

3 experiments out of 9 with pebble powder (Nos. 8, 38, 43).
3 ,, ,, 10 ,, R. L. G. ,, (Nos. 1, 11, 70).
7 ,, ,, 9 ,, F. G. ,, (Nos. 16, 18, 19, 40, 42, 47, 69).

It was below 10 per cent. in—

4 experiments out of 9 with pebble powder (Nos. 7, 9, 11, 37).
5 ,, ,, 10 ,, R. L. G. ,, (Nos. 3, 39, 44, 68, 96).
1 ,, ,, 9 ,, F. G. ,, (No. 17).

There were no circumstances connected with the carrying out of the explosions, or with the collection and analysis of the residues, to which the above great differences between the results furnished by fine grain powder and by the two large grain powders could be ascribed.

While, however, certain of the great variations in the proportions of hyposulphite and sulphide, which cannot be accounted for by variations of structure of the residue or of manipulations favourable to oxidation by atmospheric agency, appear to us to demonstrate that the hyposulphite is formed in the solid residue before the explosion-vessel is opened, and indeed in such amount that it must be regarded as an important product (whether it be a primary or a secondary one), we have been anxious to obtain, if possible, some more decisive evidence as to the probable proportions of hyposulphite actually existing in the residues furnished by the explosion of gunpowder in closed vessels. We therefore varied the method of collecting and preparing the residues for analysis, in the experiments of which the following is an account:—

1. 5960 grains (386·2 grammes) of the R. L. G. and pebble powders used in these researches were fired in the large cylinder under a density of 0·40.

Immediately on opening the cylinder in each case, the solid products were as nearly as possible divided into two equal portions, consisting of the top and the bottom. Each of these portions was again divided roughly into two equal parts, one of which, in large lumps, was, as rapidly as possible (being but for a few seconds exposed to the air), sealed in dry bottles freed, or nearly so, from oxygen, the other moieties being finely ground and freely exposed to the air for 48 hours.

The only point of difference calling for remark in the appearance of the two residues was the difference in colour, the residue from the pebble being decidedly the lighter in colour, both on the surface and in fracture; but there were material differences in the behaviour of the *ground* portions of the two powder residues.

With both powders, the bottom ground portion heated very decidedly more than the top; but while, in the R. L. G., this tendency was exhibited in a remarkably low degree, with the pebble the tendency to heat was, we think, abnormally high. In the latter case, the ground deposit from the top began to heat immediately on being placed upon paper. The deposit on the apex of the cone and in the interior, where the heat was highest, changed rapidly in colour to a light yellow, tinged with green.

The ground bottom part of the residue darkened considerably during the development of heat, and an orange-coloured deposit was condensed on the surface.

When the heat was highest, a considerable quantity of vapour was given off. Its smell was very peculiar; SH_2 was distinctly perceptible, but was by no means the dominant odour.

The maximum temperature appeared to be reached at about twenty minutes after exposure. A thermometer placed in the centre indicated a temperature of over 600° F. (315° C.), and the paper on which the residue was placed was burnt through. After half an hour's exposure the deposit cooled very rapidly.

It should be observed that the physical characteristics of the ground deposit were altered very materially by the heating. When the residue is taken out of the exploding cylinder, it is difficult to pound in the mortar, being somewhat unctuous; but after the development of heat it becomes crisp, and is readily powdered.

2. In the examination that we have instituted of the products of explosion of a

sample of sporting powder (Curtis and Harvey's No. 6), and of mining powder, the following course of proceeding was adopted for the removal of the solid residue from the explosion-vessel, and its preparation for analysis :—Distilled water which had been freed from air by long-continued boiling, was siphoned into the explosion-vessel when the latter had cooled, so that air was never allowed to come into contact with the solid residue. When the cylinder was thus quite filled with water, it was closed, and set aside for sufficient time to allow the residue to dissolve completely. The solution was then decanted into bottles freed from oxygen, which were quite filled with the liquid, and carefully sealed up until required for analysis, in carrying out which the course already described was pursued.

The products obtained by the first of these modifications of the ordinary course of procedure were submitted to partial examination, the chief object being to see to what extent the proportions of hyposulphite and sulphide varied in the upper and lower portions of the residue, and the extent to which they were affected by the great difference in the mode of treatment sustained by the different portions of one and the same residue. The proportion of hyposulphite was determined in every instance, and the products were also examined in all cases for sulphide. In the first experiment the exact proportion of this latter constituent was ascertained only in one of the three portions of the residue in which it existed; it will be seen that one of the ground portions contained none. The sulphate was determined in all instances, and, in the second experiment, the proportions of carbonate existing in the upper and lower portions of the (unground) residue were ascertained. The analytical results obtained are given in the following table :—

TABLE III.—Illustrating the effects of exposure upon the proportions of hyposulphite and monosulphide in the solid products.

Description of experiment.			Percentage composition by weight of solid residue.				
			Potassium sulphate.	Potassium hyposulphite.	Potassium monosulphide.	Sulphur.	
EXPERIMENT No. 121.							
R. L. G. powder, Waltham Abbey make . . . . Proportion of space occupied by the charge in the chamber about 40 per cent.	Top portion of residue	Unground	12·14	5·83	Large quantity	not determined	
		Ground	11·52	27·52	none		
	Bottom portion of residue	Unground	10·85	8·51	19·76	5·0	
		Ground	10·87	36·34	under 3 per cent.		
EXPERIMENT No. 122.							
Pebble powder, Waltham Abbey make . . . . Proportion of space occupied by the charge in the chamber about 40 per cent.	Top portion of residue	Unground	14·08	5·01	13·26	8·71	Carbonate of potassium 58·9
		Ground	16·22	31·06	none		
	Bottom portion of residue	Unground	13·80	6·46	16·12	7·49	Carbonate of potassium 56·06
		Ground	16·62	32·91	none		

It will be seen from the foregoing numerical results that in both experiments those portions of the residue which were exposed to the air only for a few seconds, and of which only small surfaces *were* thus exposed (as they were collected in large lumps), contained hyposulphite ranging in amount from 5 to 8·5 per cent. Those portions which were specially treated for the purpose of favouring to the utmost the formation of hyposulphite from sulphide through atmospheric agency, contained, as was to be expected, very large proportions of the former, while the latter had entirely disappeared in three out of the four portions of very finely pulverised residue. In the fourth, however, even after its free exposure to air for forty-eight hours, there still remained nearly 3 per cent. of sulphide. Now, as in no single instance in the entire series of our experiments did any accidental circumstances occur which even distantly approached the special conditions favourable to the oxidation of the sulphide which were introduced into these particular experiments, we consider ourselves justified in arriving at the conclusion that the total absence of sulphide in the residues furnished by the fine grain powder in experiments 40, 42, and 47 was not due to accident in the manipulations, and that in those residues in our series of analyses which were found to contain large quantities of hyposulphite (as in six out of the nineteen experiments with pebble and R. L. G. powder, and eight out of the nine with F. G. powder) a great proportion, at any rate, of that hyposulphite existed in those particular residues before their removal from the explosion-vessel. The circumstance that the residues furnished by our two most recent experiments (with sporting powder and mining powder), in the treatment of which the possibility of accidental formation of hyposulphite was altogether guarded against, contained 4, and about 6, per cent. of hyposulphite, demonstrates that even under these conditions a very notable quantity of that substance is found in powder-residue; but it cannot, we consider, be taken to support the view that, in a residue containing a much higher proportion of hyposulphite, the existence of the whole or a large part of that excess is ascribable to accident of manipulation. In the series of experiments with pebble powder there were three, in that with R. L. G. powder four, while in that with F. G. powder there was one, of which the residues contained proportions closely similar to those furnished by the two experiments above quoted, there being no peculiarity in those seven experiments nor any attendant circumstances which could be assigned as a possible reason why the proportions of hyposulphite in those cases should be so much lower than in the other experiments with the same powders, carried out under the same conditions. We therefore cannot but conclude that the production of a small or of a large proportion of hyposulphite (whether as a primary or secondary product, *but before the explosion-vessel is opened*) is determined by some slight modification of the conditions attending the explosion itself.

From an examination of the proportions of potassium sulphate found in the different parts of the two residues, it will be seen that in the case of the R. L. G. there was a variation of only 1·27 per cent. in the sulphate in different parts of the residue, and that in the top and bottom portions the amounts found in the unground and ground parts were almost identical, so that the proportion of sulphate was in no way affected by the prolonged exposure of the finely-ground residue to air. In the pebble powder experiment the sulphate varied in the different parts to the extent of 2·82 per cent., and the higher proportions happened to exist in the ground parts of this residue; but the differences can scarcely be considered sufficiently important to ascribe them to any other cause than a little variation in the composition of different parts of this residue.

Some of the later of our experiments with R. L. G. powder given in the first memoir furnished products which, when calculated upon the results of analysis made at the commencement of these researches, of a sample of the powder taken from the upper part of the contents of the barrel, presented greater discrepancies in some points than was the case with some of the earlier products. It was, therefore, considered desirable to repeat the analysis of this powder, operating upon a sample taken from the *lower* part of the barrel. The results of the two analyses are as follows:—

Components, per cent.		R. L. G. powder.			
		From upper part of barrel.		From lower part of barrel.	
Saltpetre			74·95		74·430
Potassium sulphate			0·15		0·133
Sulphur			10·27		10·093
Charcoal	Carbon	10·86	13·52	12·398	14·286
	Hydrogen	0·42		0·401	
	Oxygen	1·99		1·272	
	Ash, &c.	0·25		0·215	
Water			1·11		1·058

The foregoing numbers, which are in each case the means of two very concordant analyses, present sufficient differences to establish a small but decided variation in the composition of this powder, of which, be it remembered, very considerable quantities were employed in the course of the series of experiments. It appeared to us, therefore, that we were warranted in calculating the earlier results obtained with this powder (produced in 10 to 40 per cent. space) upon the composition as represented by the first analysis, and in recalculating the later ones furnished by the lower part of the contents of the barrel upon the analysis of the sample taken from that part of the powder.

In completing these researches it appeared to us of interest to include two other descriptions of gunpowder in our series of experiments, one of them a representative of the sporting powder class, the other representing the higher qualities of blasting or mining powder, which are well known to differ very materially in composition from the powders used for military purposes. The composition of these two samples of powder, which were obtained from Messrs. CURTIS and HARVEY, is given in the following tabular statement:—

Components, per cent.		Sporting powder. CURTIS and HARVEY'S No. 6.		Mining powder.	
Saltpetre			74·40		61·66
Potassium	Sulphate		0·29		0·12
	Chloride		Trace.		0·14
Sulphur			10·37		15·06
Charcoal	Carbon	10·66	13·78	17·93	21·41
	Hydrogen	0·52		0·66	
	Oxygen	2·29		2·23	
	Ash	0·31		0·59	
Water			1·17		1·61

It will be seen that the sporting powder did not differ very widely in composition from the several military powders of Waltham Abbey manufacture, while the mining powder presents very important differences from any of the other powders experimented with by us, as well as from those used by recent foreign experimenters, to which we have referred in our first memoir.* The proportion of saltpetre is about 11·3 per cent. lower than in the military powders, while the proportions of charcoal and sulphur are each higher by about one-half. The percentage composition of the charcoal contained in these two powders is given below, and a comparison of the numbers with those furnished by analysis of the charcoal from the several military powders shows that the sporting powder charcoal is intermediate between the R. F. G. and F. G. charcoal, and that the mining powder charcoal resembles that contained in the pebble powder. Both these charcoals contained, however, a decidedly higher proportion of mineral constituents than the charcoal manufactured at Waltham Abbey.

PERCENTAGE composition of the charcoals contained in the several descriptions of gunpowder employed.

	Pebble.	R. L. G.	R. F. G.	F. G.	CURTIS and HARVEY.		Spanish.
					Sporting.	Mining.	
Carbon	85·26	80·32	75·72	77·88	77·36	83·74	76·29
Hydrogen	2·98	3·08	3·70	3·37	3·77	3·07	3·31
Oxygen	10·16	14·75	18·84	17·60	16·62	10·45	14·87
Ash	1·60	1·85	1·74	1·15	2·25	2·74	5·53

The results obtained by firing these two gunpowders in 30 per cent. space are included in the statements given in Tables I. and II.†

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* Phil. Trans., 1875, Part I., p. 72.

† See also Tables XII. and XIII.

It will be remembered that a special method of collecting for analysis the solid products furnished by these powders was adopted, with the object of altogether guarding against the possibility of accidental conversion of sulphide into hyposulphite. The analytical results show that the chief differences between the results of explosion of the sporting powder (in 30 per cent. space) and of the R. F. G. powder (in 70 per cent. space) consisted, as regards the gaseous products, in the slightly higher proportion of carbonic anhydride and in the very decidedly larger amount of marsh gas furnished by the former, and, as regards the solid products, in the higher proportion of sulphide and lower proportion of hyposulphite; the quantities of these constituents of the residue are very similar to those found in the R. L. G. residue exploded in 80 per cent. space.

The gaseous and solid products of explosion of the mining powder differed very greatly, as was anticipated, from those furnished by all the other powders, as regards their proportions. The carbonic oxide was double the highest amount furnished by any of the other powders, while the carbonic anhydride, which in the three series of experiments ranged from 45 to 53 per cent. of the total volume of the gases, amounted only to 32 per cent., the two gases existing in about equal proportions. Marsh gas and hydrogen were present in unusually high proportions, and the sulphuretted hydrogen amounted to 7 per cent., being nearly double the highest proportion found in all the other experiments. The solid residue presented very interesting points of difference. The potassium carbonate was, as might have been anticipated, comparatively small in amount (though some of the experiments with F. G. powder gave similar results in this respect), but there was only 0·5 per cent. of sulphate formed, while the monosulphide amounted to 33 per cent. of the solid residue, and the free sulphur to nearly 13 per cent. FEDEROW's experiments are the only ones in which so high a (and indeed a somewhat higher) percentage of sulphide is recorded, and among the several experiments with R. L. G. powder, in which only small proportions of sulphate were formed, there was only one residue in which the free sulphur was as high in amount as that formed in the mining powder residue. It will be seen that the hyposulphite amounted to nearly 6 per cent.: 2 per cent. more than was furnished by the sporting powder under *precisely* similar conditions of experiment, and *double* the smallest amount formed in any of the series of experiments, conducted without the very special precautions which were applied in dealing with the residue of the powder under discussion. The ammonium sesquicarbonate was considerably higher in amount than in any other experiments (though still much below the amounts found by KAROLYI and LINCK), and the potassium sulphocyanide amounted to 3 per cent., or about five times the amount found in any other experiments excepting that of LINCK.

Lastly, there was a much more considerable amount of charcoal in this experiment than in any other.

It need scarcely be stated that the very distinctive difference between the composition of the solid and gaseous products of this powder are, generally, such as would have been predicted from the comparatively small proportion borne by the oxidising agent to the oxidisable constituents in the mining powder.

It will be seen presently that the experiments with mining powder presented other features of great interest in addition to those elicited by the chemical examination of the products of explosion. In concluding our observations on these, we should point out that fresh confirmation is afforded by this experiment of the fact insisted upon by us, namely, that hyposulphite must be classed among the invariable* products of explosion of gunpowder in closed spaces.

An examination of the three complete series of results obtained by the explosion of pebble, R. L. G., and F. G. powders in closed spaces in which their gravimetric densities varied from 0·1 to 0·9 per cent. of the space, and which are given in detail in Tables I. and II.,† suggests the following observations additional to those included in our first memoir, on the nature and relations to each other of the *solid* products furnished by the several powders.

Comparing the highest, lowest, and mean proportions of the chief solid products furnished by the three powders, which differed but little in composition from each other, the following points are observed :—

1. The proportions of *potassium carbonate* furnished by R. L. G. and by P. powder are very similar, while the highest, lowest, and mean results furnished by F. G. are all decidedly lower than those from the other two powders.

2. The mean proportions of *sulphate* furnished by P. and R. L. G. are not far different, though the highest amount furnished by the *former* is considerably below, and the lowest number considerably above the corresponding numbers furnished by R. L. G. powder. But the mean and the lowest proportions of *sulphate* furnished by F. G. is very considerably higher than the corresponding numbers obtained with the two other powders (the *highest* amounts obtained with F. G. and R. L. G. being identical).

The generally greater extent to which the sulphur has undergone *complete* oxidation in the case of the F. G. powder is certainly not a result which can be in the least ascribable to accidental circumstances attending the experiments, and the fact that it corresponds with the generally higher proportions of hyposulphite furnished by this powder affords additional support to the view which we maintain, that the production of the latter substance, in variable, and sometimes very considerable amounts from the powders experimented with, is not to be explained away by ascribing it to accident of manipulation.

3. It will be seen that, whereas the means of the amounts of hyposulphite obtained in the analyses of the residues from pebble and R. L. G. powders are almost identical, they amount to little more than half that of the mean numbers furnished by the

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[*] See note at end of this paper.

[†] See also Tables XII. and XIII.

analyses of the F. G. residues. But the highest result furnished by pebble powder is nearly equal to, and that furnished by R. L. G. powder is not far below the highest number obtained with F. G. powder.

4. As regards potassium monosulphide, the mean result in the case of pebble is very considerably higher than that furnished by R. L. G. powder, and more than four times the mean result given by F. G. powder. It is noteworthy, too, as indicative of the great and apparently uncontrollable irregularity in the amount of this product formed by the explosion of powders of normal composition in closed spaces, that the proportions of sulphide produced from pebble powder at the higher pressures were very small, and similar to those formed from F. G. powder at low as well as high pressures (except where none was found in the residues), and that in several instances very considerable quantities were formed from Pebble at densities ranging from 20 to 60 per cent., some of them being indeed very much higher than that produced in the special experiment with sporting powder, in which extra precautions were adopted to guard against oxidation of sulphide. Then, in the case of R. L. G. powder, the proportions of sulphide found may be said to be intermediate between those produced from pebble and F. G., the amounts ranging from 2 to 10 per cent.; and the higher and lower proportions are indiscriminately distributed through the different residues obtained at low, high, and intermediate pressures. In no instance, either with pebble or R. L. G., was there a complete absence of sulphide, as in *three* instances, at the higher pressures, with F. G. powders. We feel bound again to lay stress upon the fact that there were no accidents of manipulation to account for these remarkable differences in residues furnished by powders of practically the same composition.

5. One or two other points of interest present themselves in connexion with the potassium sulphate found in the residues from the three powders. Both in the pebble and F. G. residues, those obtained at the lowest and the highest densities differed very decidedly from the remainder in regard to the sulphate present, while the proportions in the residues obtained at the densities intermediate between those two extremes present comparatively slight differences in the case of both these powders. But the residues furnished by R. L. G. powder exhibit a very decided difference to the above; the proportions of sulphate in those produced at the four lowest pressures (up to a density of 40) are high, and very similar in amount to those found in the majority of the F. G. powder-residues, while those in the residues produced at the six higher pressures are only from one-fourth to one-half in amount of the others, some being similar to, and others still lower than those formed in the pebble powder-residues. On comparing the proportions of hyposulphite and sulphide in these R. L. G. residues with the sulphate, it will be seen that they vary as much among themselves in the residues where the proportion of sulphate is high as in those where it is small in amount. That the amount of sulphate produced by the explosion of this particular powder, even under the same conditions as regards pressure, was liable to considerable variation, is demonstrated by comparing the results of special examination of the residue

obtained by its explosion in 40 per cent. space (as given in Table III., page 215) with those in the general series (Tables I. and II.) furnished by the same powder, fired in the same space. In the one instance 22·87 per cent. of sulphate were found, in the other it was barely half that amount. With such variations occurring in the proportion of *sulphate* formed under like conditions of explosions, it can hardly be matter for surprise that variations of the same kind should occur in the proportions of sulphide and hyposulphite. In fact, in the two parallel experiments now referred to, the amount of sulphide contained in the residue rich in sulphate was only about one-fifth that contained in the other residue, the proportion in this being higher than any in the three series of analyses. Be it observed, at the same time, that this high amount cannot be ascribed to the adoption of any special precautions to prevent accidental oxidation of the sulphide in the special experiment in which it was found, as there were several residues in the series furnished by *pebble* powder (of the same composition as the R. L. G.) which contained proportions of sulphide not much lower than in this particular case.

Two other parallel experiments (39 and 96) with R. L. G. conducted in 60 per cent. space, exhibit, on the other hand, a remarkably close concordance in regard to the proportions of sulphate and hyposulphite (the numbers being almost identical), though there was a decidedly higher proportion of sulphide in the one than in the other, and a not unimportant difference in the proportions of the gaseous constituents.

With regard to the results of the special experiment with *pebble* powder (p. 215) conducted in 40 per cent. space, and the parallel experiment in the series of pebble powder results, it will be seen that the amounts of sulphate formed in the two experiments were closely similar. The proportions of sulphide and hyposulphite found in the residue of the special experiment correspond very well with the results obtained with this powder at the two lower and the next higher densities, which is not the case with the parallel experiment in the series (No. 12, 40 per cent.), and this may possibly indicate that, in the latter, there may have been an exceptionally considerable conversion of sulphide into hyposulphite during the removal of the residue from the explosion-vessel, it being borne in mind that marked differences in the behaviour and appearance of the residues (even those resulting from the service powder) were frequently noted at the time of collection.

Before leaving this part of our subject we may remark that we have placed in the appendix to this memoir a statement in which we have given for every analysis we have made, the results of the following rather laborious calculations, which have been made in the manner described in our first memoir.*

(1) The amount of gaseous products calculated from the data furnished by the analysis of the solid products.

(2) The amount of solid products calculated from the data furnished by the analysis of the gaseous products.

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* Phil. Trans., 1875, Part I., p. 90.

(3) A comparison between the weights of the elementary substances found in the products of combustion and the weights of the same elements found in the powder prior to ignition.

(4) The weight of oxygen contained in the total quantity of hyposulphite found.

An examination of this statement will show how closely accordant the various analyses are as a whole; but in estimating the degree of accuracy attained, the following points must carefully be borne in mind.

1. That in the very large quantity of powder used, slight variations in its composition (as indeed have been found) were sure to exist.

2. That we have adopted as one of the data of our calculations the average quantity of gas found to be produced by the explosion. But, as we have elsewhere pointed out, our investigations seem to prove that exceedingly slight and inappreciable variations in the circumstances of explosion give rise to very notable changes in the products, and among others in the amount of gaseous products. Any change in this direction would of course affect the accordance of the analysis in which the abnormal decomposition occurred.

A review of the comparison between the weight of oxygen originally in the powder, and the weight found in the products of explosion, appears to show that there is in the former, on the average, a very appreciable excess of oxygen. Hence it may pretty fairly be concluded that a portion of the hyposulphite found is due to the oxidation of the monosulphide after removal from the explosion-vessel.

On the other hand, a reference to those analyses in which hyposulphite exists in *large* proportion, shows that were we to assume the whole of the hyposulphite as formed after the removal of the products from the cylinders, there would exist a deficiency in oxygen much larger than the existing excess. Hence we may equally fairly, from this line of argument, conclude that it is impossible to attribute to accidental causes the formation of the whole of the hyposulphite, and that a considerable proportion of it *must* be looked on either as a primary or secondary product.

We now pass to the question of the amount of heat generated by the combustion of gunpowder, and in so doing we may remark that we were fully cognisant of the inconveniences inseparable from the form of apparatus used by us for this purpose and described in our first memoir.* In fact, the errors likely to arise from its use were very exactly pointed out by ourselves,† and we were quite aware of the great advantages in regard to saving of time and labour, and to accuracy, that would result from the use of apparatus similar to that which we shall presently describe.

But the apparatus, such as it was, was deliberately adopted, because at the time when these experiments were made we could not be sure that the decomposition experienced by gunpowder in its explosion when fired in considerable quantities and under tensions similar to those existing in the bores of guns was by any means the same as that occurring when it is fired in small quantities and under feeble tensions.

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* Phil. Trans. 1875, Part I., p. 63.

† *Loc. cit.*, same page.

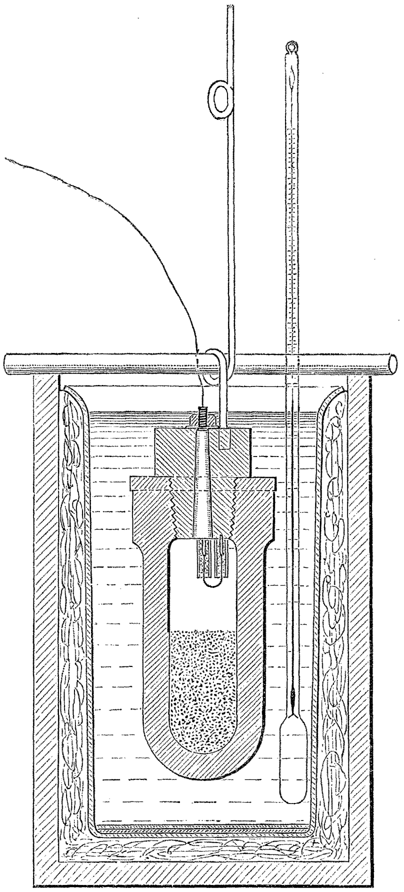
In fact, one of the principal objects of our experiments was to determine this very point, and we therefore considered it necessary, at all events in the first instance, to determine the heat generated when gunpowder is fired in considerable quantities and under high tensions.

To do this, vessels of great strength, consequently of great weight, and therefore not well suited for calorimetric observations, were necessary.

It will presently be seen, however, that the difference between the determinations made by us and those of the other experimenters alluded to by General MORIN and M. BERTHELOT are due, not to error in our determinations, but to essential and striking differences in the decomposition of different descriptions of powder.

The conclusion of the whole of our analyses (of which a complete table is given at p. 207 of this memoir) has shown that, with certain slight exceptions, to which we have elsewhere adverted, the products of combustion are not seriously affected either by differences in the quantity or the gravimetric density of the charge exploded. It would appear indeed as if there were occasionally quite as great differences in the transformation which takes place between charges exploded as nearly as possible under the same circumstances and others exploded under widely different conditions.

We were therefore enabled in the experiments which we are about to describe to make use of the following apparatus.



Two explosion-vessels, both of the general form shown in the annexed figure, but weighing, one, 21,311·6 grs. (1381 grms.), with a capacity of 501·54 grs. (32·50 grms.), the other weighing 52,931·6 grs. (3430 grms.), with a capacity of 1833·75 grs. (118·83 grms.), were prepared. The specific heats of both these vessels were carefully determined, and the amount of heat absorbed by the calorimeter for various changes of temperature was also carefully determined, and corresponding tables for convenient use formed. Thermometers specially made for the purpose and capable of being read to 0°·01 F. (0°.0055 C.) were used in these experiments.

Full details of the determination of the specific heat of the vessels and of the absorption of the heat by the calorimeter are given in the appendix, pp. 264 to 267.

To determine the heat generated, a charge of from 150 to 200 grs. (9·72 to 12·96 grms.) in the smaller cylinder, of 400 grs. (25·92 grms.) in the larger cylinder, was carefully weighed and placed in the explosion-vessel. The explosion-vessel was then immersed in the water of the calorimeter and the charge fired in the usual way, the attached thermometer being read before the explosion, and afterwards continuously until the maximum temperature (which was usually reached in about 2 minutes) was attained.[*]

In order to make our new calorimetric determinations as complete as possible, and with the view of exhibiting the differences in the heat evolved due to changes in the composition of the powder, we have not only found separately the heat given off by the three principal powders described in our first memoir, but have added to these three other powders differing widely in their composition, viz.: ordinary English mining, CURTIS and HARVEY'S well-known powder No. 6, and Spanish spherical. The composition of all these powders has been already given either in the present or in our former memoir. But for our present purpose it is convenient to place in juxtaposition the composition of these six powders.

TABLE IV.—Exhibiting the differences in the composition of the powders experimented with which are described in this memoir.

Nature of powder.	Saltpetre.	Sulphate.	Potassium Chloride.	Sulphur.	Carbon.	Hydrogen.	Oxygen.	Ash.	Water.
Pebble powder	·7467	·0009	..	·1007	·1212	·0042	·0145	·0023	·0095
R. L. G., W. A.	·7443	·0013	..	·1009	·1240	·0040	·0127	·0022	·0106
F. G., W. A.	·7355	·0036	..	·1002	·1136	·0049	·0257	·0017	·0148
CURTIS and HARVEY'S No. 6 .	·7440	·0029	Trace	·1037	·1066	·0052	·0229	·0031	·0117
Mining powder	·6166	·0012	·0014	·1506	·1793	·0066	·0223	·0059	·0161
Spanish spherical	·7530	·0027	·0002	·1242	·0865	·0038	·0168	·0063	·0065

The decomposition they experienced is exhibited in Tables I.[†] and II. of the present memoir.

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[*] It is scarcely necessary to state that the correction for the absorption of heat by the calorimeter and the effect of cooling was in all cases made.

[†] See also Tables XII. and XIII.

With the small explosion-vessel the results obtained (experiments 146 to 166) were as follows, the numbers given below indicating the gramme units of heat evolved by the combustion of 1 gramme of each description of powder employed:—

Nature of powder.	Gramme-units of heat evolved.				
	I.	II.	III.	IV.	Means.
Pebble	711·9	734·1	694·4	710·0	712·6
R. L. G.	725·1	718·4	707·5	. .	717·0
F. G.	706·5	738·9	731·7	. .	725·7
CURTIS and HARVEY'S No. 6 .	784·0	755·7	744·9	732·9	754·3
Mining	512·7	505·5	507·9	. .	508·7
Spanish	762·5	771·4	753·4	. .	762·4

With the larger explosion-vessel the results of experiments 171 to 179 and 181 to 192 gave

Nature of powder.	Gramme-units of heat evolved.			
	I.	II.	III.	Means.
Pebble	728·5	714·7	703·4	715·5
R. L. G.	713·4	724·7	717·7	718·6
F. G.	731·1	722·1	730·7	728·0
CURTIS and HARVEY'S No. 6 .	751·3	765·3	750·6	756·1
Mining	520·0	507·0	499·6	508·9
Spanish	771·3	761·8	754·0	762·3

From the whole of these experiments, and giving to the second series, as probably the more accurate, twice the weight of the first series, we arrive at the conclusion that the heat generated by the combustion of the powders *as actually used* is as follows:—

1 gramme of pebble powder generates 714·5 gramme-units
1 ,, ,, R. L. G. ,, ,, 718·1 ,, ,,
1 ,, ,, F. G. ,, ,, 727·2 ,, ,,
1 ,, ,, C. and H. No. 6 ,, 755·5 ,, ,,
1 ,, ,, mining ,, ,, 508·8 ,, ,,
1 ,, ,, Spanish ,, ,, 762·3 ,, ,,

From an examination of the whole of the above results it is obvious: Firstly, that the heat generated by the combustion of gunpowder is subject to very wide variations, dependent upon the particular nature* of the powder employed (the Spanish

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* Both physical and chemical.

powder, for example, generates just 50 per cent. more heat than the mining powder); and, secondly, that the heat evolved by the same description of powder varies in different experiments to a greater extent than is to be accounted for by errors of observation. And this was, indeed, to be expected, since the very considerable variations in the products of combustion, under the same circumstances, as disclosed by our analyses, could hardly be supposed to exist without some corresponding variation in the heat evolved.

Our views on this head are confirmed by the calorimetric determinations we have made in our researches on gun-cotton. In these determinations, which have been carried on with precisely the same apparatus, we have found no appreciable difference in the heat evolved in the various experiments. The deduction is that the discrepancies between the several observations in the case of gunpowder are due to differences in the metamorphoses, not to defects in the observations.

The units of heat liberated given above are those furnished by the powders as actually used; but as these powders had different amounts of moisture in their composition, and as, in use, these amounts of moisture are found to vary considerably, giving rise, especially when the powders are used in guns, to very different pressures, and generating very different energies, we have considered it desirable to correct the above figures, and we place below those that would have had place had the powders, when fired, been perfectly free from moisture.

TABLE V.—Showing the heat, in gramme-units, generated by the combustion of 1 gramme of the undermentioned perfectly dry powders.

1	gramme	pebble powder . . .	generates	721·4	gramme-units.
1	„	W. A. R. L. G. powder	„	725·7	„
1	„	W. A. F. G. powder .	„	738·3	„
1	„	C. and H. No. 6 powder	„	764·4	„
1	„	mining powder . . .	„	516·8	„
1	„	Spanish pellet powder .	„	767·3	„

The data for computing the mean specific heats of the products of explosion of the six powders, as well as the results of the necessary calculations, are given in the annexed Table, No. VI.

TABLE VI.—Giving data and results of calculation of the mean specific heats (at natural temperatures) of the products of explosion of the six powders experimented with.

Products of combustion.	A. Specific heat.	Pebble, W. A.		R. L. G., W. A.		F. G., W. A.		CURTIS and HARVEY'S No. 6.		Mining.		Spanish spherical.	
		1. Weight in a gramme.	Product of columns A. and 1.	2. Weight in a gramme	Product of columns A. and 2.	3. Weight in a gramme.	Product of columns A. and 3.	4. Weight in a gramme.	Product of columns A. and 4.	5. Weight in a gramme.	Product of columns A. and 5.	6. Weight in a gramme.	Product of columns A. and 6.
Carbonic anhydride . . .	·172	·2651	·04560	·2608	·04486	·2634	·04530	·2606	·04482	·2290	·03939	·2438	·04193
Carbonic oxide	·174	·0473	·00823	·0418	·00727	·0348	·00605	·0248	·00431	·1531	·02664	·0140	·00244
Nitrogen	·173	·1110	·01920	·1106	·01913	·1100	·01903	·1137	·01977	·0861	·01489	·1097	·01898
Sulphydric acid	·184	·0110	·00202	·0107	·00197	·0100	·00184	·0083	·00153	·0391	·00719	·0097	·00178
Marsh gas	·468	·0006	·00028	·0008	·00037	·0003	·00014	·0046	·00215	·0071	·00332	..	..
Hydrogen	2·411	·0006	·00145	·0005	·00121	·0007	·00169	·0008	·00193	·0017	·00410	·0003	·00072
Oxygen	·155	..	..	·0002	·00003	·0003	·00005	..	..	..	..	·0007	·00011
Potassium carbonate . . .	·206	·3226	·06646	·3392	·06987	·2804	·05776	·3436	·07078	·1970	·04058	·2173	·04476
,, sulphate . . .	·196	·0703	·01378	·0838	·01642	·1225	·02401	·1258	·02466	·0028	·00055	·2962	·05805
,, hyposulphite . .	·197	·0789	·01554	·0760	·01497	·1440	·02837	·0231	·00455	·0281	·00554	·0473	·00932
,, monosulphide .	·108	·0574	·00620	·0360	·00387	·0140	·00151	·0589	·00636	·1612	·01741	·0197	·00213
,, sulphocyanate .	·200	·0016	·00032	·0013	·00026	·0007	·00014	..	..	·0140	·00280	·0003	·00006
,, nitrate	·239	·0013	·00031	·0015	·00036	·0009	·00021	·0017	·00041	·0004	·00010	·0058	·00139
,, oxide	·200	·0009	·00018	..	..	·0075	·00150	..	..	..	..	..	..
,, sesquicarbonate .	·350	·0005	·00017	·0004	·00014	·0003	·00010	·0005	·00018	·0085	·00298	·0002	·00007
Sulphur	·171	·0309	·00528	·0357	·00610	·0102	·00174	·0336	·00575	·0623	·01065	·0350	·00598
Charcoal	·242	..	..	·0007	·00017	..	..	..	..	·0096	·00232	..	..
Mean specific heats . . .	..	..	·18503	..	·18704	..	·18946	..	·18720	..	·17846	..	·18773

There is no material difference in the specific heats if the hyposulphite be supposed to be an accidental product formed by the oxidation of the sulphide.

We have pointed out in our first memoir our reasons for considering fallacious a temperature of explosion deduced (as has been done by some authors) by dividing the number of gramme units of heat by the mean specific heat of the exploded powder at 0° C.; but for purposes of comparison, to exhibit the striking differences between the powders, as well as because we have not data at our disposal to enable us to deduce the actual temperature of explosion in the case of each of the six powders, we give below the temperature of each powder calculated upon the above hypothesis.

They are as follow:—

Temperature of explosion on above hypothesis of

W. A. pebble powder	. . . .	3899° C.
W. A. R. L. G. ,,	. . . .	3880 ,,
W. A. F. G. ,,	. . . .	3897 ,,
C. and H. No. 6 ,,	. . . .	4083 ,,
Mining ,,	. . . .	2896 ,,
Spanish pellet ,,	. . . .	4087 ,,

The volumes of the permanent gases generated by the explosion of each of the six powders are as follow:—

1	gramme	of	W. A. pebble	powder	generated	275·7	cubic	centimetres
1	,,	,,	W. A. R. L. G.	,,	,,	271·3	,,	,,
1	,,	,,	W. A. F. G.	,,	,,	259·2	,,	,,
1	,,	,,	C. and H. No. 6	,,	,,	238·2	,,	,,
1	,,	,,	mining	,,	,,	354·6	,,	,,
1	,,	,,	Spanish pellet	,,	,,	232·7	,,	,,

The above volumes are all calculated for a temperature of 0° C. and a barometric pressure of 760 millims. of mercury.

If we correct, as before, the quantities of permanent gases formed for the amounts of moisture contained in the powders when experimented with, we shall have the values given in Table VII.

TABLE VII.—Giving the volumes of permanent gases generated by the explosion of 1 gramme of the undermentioned perfectly dry powders.

1	gramme	W. A. pebble	powder	generates	278·3	cubic	centimetres.*
1	,,	W. A. R. L. G.	,,	,,	274·2	,,	,,
1	,,	W. A. F. G.	,,	,,	263·1	,,	,,
1	,,	C. and H. No. 6	,,	,,	241·0	,,	,,
1	,,	mining	,,	,,	360·3	,,	,,
1	,,	Spanish pellet	,,	,,	234·2	,,	,,

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* It is perhaps necessary to remind readers not familiar with the French metrical system that the assertion that a gramme of powder generates 278·3 cubic centimetres of permanent gases at temperature

It is of high importance to observe that the volume of the permanent gases generated is in every case in inverse ratio to the units of heat evolved. Thus, if Tables V. and VII. be compared, and if from Table V. we arrange the powders in descending order of units of heat, we have the order exhibited in Table VIII.; and if from Table VII. we place the powders in ascending order of volumes of gas produced, we find that we have precisely the same arrangement.

TABLE VIII.—Showing the arrangement of the six powders when placed either according to the amount of heat generated in a descending, or according to the quantity of gas evolved in an ascending, scale.

Nature of powder.	Units of heat per gramme exploded.	Cubic cents. of gas per gramme exploded.
Spanish pellet powder	767·3	234·2
CURTIS and HARVEY'S No. 6 powder ..	764·4	241·0
W. A. F. G. powder	738·3	263·1
W. A. R. L. G. powder	725·7	274·2
W. A. pebble powder	721·4	278·3
Mining powder	516·8	360·3

The results given in this table are very striking. If we take the two natures which commence and close the list, it will be observed that on the one hand the heat generated by the Spanish powder is about 50 per cent. higher than that generated by the mining powder, and that on the other hand the quantity of permanent gases evolved by the mining powder is about 50 per cent. greater than that given off by the Spanish.

Thus it appears that the great inferiority of heat developed by the mining as compared with the Spanish powder is compensated, or at least approximately so, by the great superiority in volume of permanent gases produced. A similar relation is observed in respect to the other powders, and it may indeed be noted that the products of the figures given in columns 2 and 3 in Table VIII. do not differ greatly from a constant value; thus pointing towards the conclusion that the pressures at any given density and the capacity for performing work of the various powders are not very materially different.

This fact has been entirely verified for the whole of the Waltham Abbey powders, and in a less degree for the three other powders also.

Thus at the points where the Spanish, mining, and CURTIS and HARVEY'S No. 6 powders have been compared with the standard pressure curves determined from

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and pressure specified, is equivalent to the assertion that the permanent gases occupy 278·3 times the space which the powder occupied in its unexploded state, the gravimetric density of the powder being assumed to be unity.

Waltham Abbey powder, the agreement is very close ; the departure from the normal curve not in any case exceeding that obtained in particular experiments with the Waltham Abbey powders themselves.

With respect to the pressure given by mining powder, the peculiarities shown by this powder were so interesting that it appeared to us important to determine its tension when fired under a high gravimetric density. We accordingly fired (experiment 230) 11,560 grs. (749 grms.) of this powder under a gravimetric density of unity.

The pressures developed by two very accordant observations was, when corrected, 44 tons on the square inch (6706 atmospheres). The pressure obtained under similar circumstances from Waltham Abbey powder was 43 tons on the square inch (6554 atmospheres).

It will afterwards be seen that the capacity for performing work of the various descriptions of powder is also not very different, and this similarity of result is the more remarkable when it is remembered that with, at all events, three of the powders, there were striking differences both in their composition and in the decomposition that they experienced, and when, in consequence, material variations both in pressures at different densities and in potential energy might have been expected.

But returning to the great difference in heat evolved, for example, by the Spanish and mining powders, we think it is difficult to resist the conclusion that the small number of units of heat evolved by the latter is in great measure due to the quantity of heat that has been absorbed in placing the very much larger proportion of the products of combustion in the form of permanent gases. This suggestion would, we think, also fully explain the fact alluded to in our first memoir,* and to which we had been led purely by experiment, namely, " that the variations observed by us in the decomposition of gunpowder do not, even when very considerable, materially affect either its tension or capacity for performing work."

The above facts and remarks would also show that a comparison between different gunpowders, or a comparison between gunpowder and other explosive agents cannot, as has been proposed,† be determined by a simple measurement of the corresponding units of heat they evolve.

Did such a law hold, the Spanish powder should have more than 50 per cent. advantage over the mining powder, but as a matter of fact, although not very widely different, the mining powder had the advantage both in respect to the tension observed in a close vessel and to the energy developed in the bore of a gun.

As regards the *actual* temperature of explosion, we have little doubt, from the results of the further experiments detailed in this paper, that the temperature named in our first memoir, viz., 2200° C., is not far removed from the truth for the principal powders with which we were then experimenting.

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* *Loc. cit.*, p. 88.

† DE TROMENEC, 'Comptes Rendus,' tom. lxxvii., p. 128.

That temperature may not improbably be taken at the high limit of the temperature of explosion for the Spanish pellet, which, as conjectured by us, has been proved to have developed a higher temperature than any other powder with which we have experimented.

The complete fusion of the platinum with this powder, and with this alone, is thus shown not to be an isolated or accidental occurrence, but to depend on a real difference of temperature, and we are thus by two converging lines of reasoning brought to the conclusion that for pebble or R. L. G. powder the temperature of explosion may be taken as a little above the melting point of platinum, say about 2100° C., while the temperature of explosion of a powder like the Spanish pellet may be taken as occasionally ranging up to 2200° C.

The data at our disposal are not sufficient to enable us to determine the temperature of explosion of the English mining powder with the same accuracy, but it is probable that 2000° C. and 1800° C. may be assigned as the limits between which the true temperature may be placed.

After our remarks on the slight differences or accidents which appear to give rise to not inconsiderable variations in the products of decomposition of gunpowder, it is hardly necessary to point out that such differences in decomposition are nearly sure to give rise to corresponding variations in the temperature of explosion, and that therefore this temperature, even in one and the same powder, cannot be supposed to be always identical.*

The relation between the tension of the gases developed by the explosion of gunpowder (when it is expanded in the bore of a gun with production of work) and the volume which these gases occupy is in our first memoir† expressed by the relation

$$\frac{p}{p_0}=\left\{\frac{v_0(1-\alpha)}{v-\alpha v_0}\right\}^{\frac{C_p+\beta\lambda}{C_v+\beta\lambda}} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (30)$$

where p is the tension of the permanent gases corresponding to volume v, C_p the specific heat of the permanent gases at constant pressure, C_v the specific heat at constant volume, α the ratio which the volume of the non-gaseous products of explosion bears to the volume of the unexploded powder, β the ratio between the weights of the non-gaseous and gaseous portions of the products of explosion, λ the specific heat of the non-gaseous products; but in that memoir the values of the constants C_p, C_v, and β were calculated from a few of the analyses that were first made. The completion of the whole of our analyses has enabled us to recalculate these three constants, and their

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* It is by no means improbable that owing to the larger proportion of carbon which assumes the higher state of oxidation as the pressure under which the explosion takes place is increased, the temperatures at high tensions may be somewhat greater than those which occur when the powder is fired under low tensions.

† Phil. Trans., 1875, Part I., p. 129.

values, together with those of the other constants used in equation (30), are given in Table IX.

With regard to the value of λ it is necessary to say a few words. If the tensions given in Table XVIII.[*] of our first memoir calculated from (30) be compared with the tensions actually observed in the bores of guns given in the same table, or if a comparison be made between curves B and C in Plate 24 of the same memoir, it will be observed that for densities of the products of combustion of ·4 and below, or, in other words, for $2\frac{1}{2}$ expansions and higher, the tensions actually observed with R. L. G. powder are in all cases higher than those calculated from equation (30). This, of course, should not be, as those last tensions should in actual practice only be reached if there were no loss from windage, vent, or other causes, if there were perfect combustion of the charge, and if the charge were expanded in a gun perfectly impervious to heat.

We surmised[†] as one of the causes of this difference that in our calculations we had taken λ at its mean value, whereas we pointed out that as the specific heat of the non-gaseous products must, according to our hypothesis, increase rapidly with the temperature, λ should for our purposes be taken at a considerably higher value.

As however the agreement between the observed and calculated tensions was exceedingly close, as when the calculations were applied to guns, the "factor of effect" alone would practically be altered, and as, finally, we had not sufficient data to enable us to correct this constant with any certainty, we did not feel justified in attempting hypothetical corrections.

But since the date of the submission of our first memoir to the Royal Society, our knowledge of the action of large charges in the bores of guns has been greatly increased; not only have charges seven or eight times as great[‡] as the largest of those then discussed been fired, but we have submitted to careful calculation, with a full knowledge of all the necessary data, the results of a very large number of rounds fired from guns of all sizes, from the 100-ton gun down to the smallest gun in H.B.M.'s service. In some of these guns also the charges were so arranged as to suffer a high degree of expansion, and we have thus accumulated data which have enabled us to deduce a corrected value of λ, and which gives pressures and energies more closely in accordance with the whole of the experiments we have discussed.

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[*] Phil. Trans., 1875, Part I., p. 129.

[†] Phil. Trans., *loc. cit.*, p. 131.

[‡] The highest charge fired by the distinguished Italian artillerists who conducted the recent experiments with the 100-ton guns reached the great weight of 260 kilos. (573 lb.) of FOSSANO powder—a powder singularly well adapted for use in large guns. The velocity given to a projectile of 908 kilos. (2001·5 lb.) was (525·9 metres) 1725·3 feet per second, and the energy of the shot at the muzzle reached the enormous amount of (12,800 metre tonnes) 41,333 foot-tons. The highest charge fired from the 80-ton gun has been (208·7 kilos.) 460 lb. prismatic powder. This charge gave to a projectile of 1705 lb. a muzzle velocity of (495·6 metres) 1626 feet per second and an energy of (9680 metre tonnes) 31,257 foot-tons.

The value of p_0, that is, the pressure corresponding to a gravimetric density of unity, is taken at 6554 atmospheres $=43$ tons per square inch, this value being the result of our further experiments corrected for perfectly dry powder.

TABLE IX.—Showing the value of the constants in equation (30).

$p_o=43$ tons per square inch $=6554$ atmospheres.
$\alpha=\cdot57$
$\beta=1\cdot2957$
$C_p=\cdot2324$
$C_v=\cdot1762$
$\lambda=\cdot45$

From equation (30), with the values of the constants given in Table IX., we have calculated the tensions for various gravimetric densities ranging from 1 to ·05, and have expressed these tensions in kilogrammes per square centimetre, in tons per square inch, and in atmospheres.

We have placed in the same table, for purposes of comparison, the pressures which would rule were the gases permitted to expand without production of work in a vessel impervious to heat, or, what amounts to the same thing, the pressures that would have place were the charges exploded in a perfectly closed cylinder with the corresponding gravimetric densities.

TABLE X.—Giving in terms of the density the tensions existing in the bores of guns calculated from equation (30); giving also the tensions if the gases are suffered to expand without production of work. In both cases the powder is supposed to be perfectly dry.

Mean density of products of combustion.	Corresponding expansions.	Tensions calculated from equation (30).						Tensions in close cylinders or where gases expand without cooling or production of work.					
		Kilos. per square cm.	Differences.	Tons per square inch.	Differences.	Atmospheres.*	Differences.	Kilos. per square c m.	Differences.	Tons per square inch.	Differences.	Atmospheres.	Differences.
1·00	1·000	6772·2		43·00		6554·0		6772·2		43·00		6554·0	
			789·0		5·01		763·6		738·6		4·69		715·9
·95	1·053	5983·2		37·99		5790·4		6033·6		38·31		5839·1	
			693·0		4·40		670·7		652·1		4·14		631·0
·90	1·111	5290·2		33·59		5119·7		5381·5		34·17		5208·1	
			609·5		3·88		589·8		579·5		3·68		560·9
·85	1·176	4680·7		29·72		4529·9		4802·0		30·49		4647·2	
			541·8		3·44		524·4		519·8		3·30		503·0
·80	1·250	4138·9		26·28		4005·5		4282·2		27·19		4144·2	
			481·9		3·07		466·4		467·7		2·97		452·6
·75	1·333	3657·0		23·22		3539·1		3814·5		24·22		3691·6	
			434·7		2·76		420·6		422·1		2·68		408·5
·70	1·429	3222·3		20·46		3118·5		3392·4		21·54		3283·1	
			390·6		2·48		378·0		385·9		2·45		373·4
·65	1·539	2831·7		17·98		2740·5		3006·5		19·09		2909·7	
			354·3		2·25		343·0		351·2		2·23		339·9
·60	1·667	2477·4		15·73		2397·5		2655·3		16·86		2569·8	
			321·3		2·04		310·9		322·8		2·05		312·5
·55	1·818	2156·1		13·69		2086·6		2332·5		14·81		2257·3	
			292·9		1·86		283·5		296·1		1·88		286·5
·50	2·000	1863·2		11·83		1803·1		2036·4		12·93		1970·8	
			267·8		1·70		259·1		274·1		1·74		265·2
·45	2·222	1595·4		10·13		1544·0		1762·3		11·19		1705·6	
			245·7		1·56		237·8		253·5		1·61		245·4
·40	2·500	1349·7		8·57		1306·2		1508·8		9·58		1460·2	
			225·2		1·43		217·9		236·3		1·50		228·7
·35	2·857	1124·5		7·14		1088·3		1272·5		8·08		1231·5	
			206·3		1·31		199·7		218·9		1·39		211·8
·30	3·333	918·2		5·83		888·6		1053·6		6·69		1019·7	
			190·6		1·21		184·4		204·7		1·30		198·2
·25	4·000	727·6		4·62		704·2		848·9		5·39		821·5	
			174·8		1·11		169·2		192·2		1·22		185·9
·20	5·000	552·8		3·51		535·0		656·7		4·17		635·6	
			160·6		1·02		155·5		179·5		1·14		173·8
·15	6·667	392·2		2·49		379·5		477·2		3·03		461·8	
			146·5		·93		141·7		168·5		1·07		163·1
·10	10·000	245·7		1·56		237·8		308·7		1·96		298·7	
			132·3		·84		128·1		159·1		1·01		153·9
·05	20·000	113·4		·72		109·7		149·6		·95		144·8	

We have shown[†] that the theoretic work which a charge of gunpowder is capable of effecting in expanding to any volume v is expressed by the equation

$$W=\frac{p_0v_0(1-\alpha)(C_v+\beta\lambda)}{C_p-C_v}\left\{1-\left(\frac{v_0(1-\alpha)}{v-\alpha v_0}\right)^{\frac{C_p-C_v}{C_v+\beta\lambda}}\right\} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \qquad (34)$$

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[*] We are indebted to Colonel ALONCLE and the Commandant HEDON, of the Marine Artillery of France, translators of our memoir, for pointing out that although we have adopted as our standard atmosphere that used in France, viz.: a barometric pressure of 760 m.m. mercury and a temperature of 0° C., the coefficient we have used in converting tons per square inch into atmospheres is not exactly in accordance with our supposition. In the present memoir this discrepancy is corrected.

[†] Phil. Trans., 1875, Part I., p. 132.

And on account of its very great utility we give in Table XI. the results of the calculations of W for various values of v up to and inclusive of $v=50$, the powder used being supposed to be of the normal type and free from moisture, and the constants having the values given in Table IX.

The work is expressed in the table both in metre tonnes per kilogramme and foot-tons per pound of powder burned, and by use of a proper factor of effect is applicable also to powders differing very materially from those of Waltham Abbey manufacture—for example, to mining or the Spanish powders.

But before entering upon these special cases we shall, as the principles embodied in this table have led to the greatly increased charges of recent guns and the consequent high velocities attained, give one or two illustrations of its application.

TABLE XI.—Giving for value of v up to $v=50$, the total work that dry gunpowder of the Waltham Abbey standard is capable of performing in the bore of a gun in metre tonnes per kilogramme, and foot-tons per lb. of powder burned.

Number of volumes of expansion.	Corresponding density of products of combustion.	Total work that gunpowder is capable of performing.			
		Per kilogramme burned in metre tonnes.	Difference.	Per lb. burned in foot-tons.	Difference.
1·00	1·000	..	..	..	..
1·01	·990	0·669	·669	·980	·980
1·02	·980	1·322	·653	1·936	·956
1·03	·971	1·960	·638	2·870	·934
1·04	·962	2·583	·623	3·782	·912
1·05	·952	3·192	·609	4·674	·892
1·06	·943	3·788	·596	5·547	·873
1·07	·935	4·370	·582	6·399	·852
1·08	·926	4·940	·570	7·234	·835
1·09	·917	5·498	·558	8·051	·817
1·10	·909	6·045	·547	8·852	·810
1·11	·901	6·581	·536	9·637	·785
1·12	·893	7·106	·525	10·406	·769
1·13	·885	7·621	·515	11·160	·754
1·14	·877	8·126	·505	11·899	·739
1·15	·870	8·622	·496	12·625	·726
1·16	·862	9·109	·487	13·338	·713
1·17	·855	9·587	·478	14·038	·700
1·18	·847	10·056	·469	14·725	·687
1·19	·840	10·517	·461	15·400	·675
1·20	·833	10·970	·453	16·063	·663
1·21	·826	11·416	·446	16·716	·653
1·22	·820	11·855	·439	17·359	·643
1·23	·813	12·287	·432	17·992	·633
1·24	·806	12·712	·425	18·614	·622
1·25	·800	13·130	·418	19·226	·612
1·26	·794	13·541	·411	19·828	·602
1·27	·787	13·945	·404	20·420	·592
1·28	·781	14·342	·397	21·001	·581
1·29	·775	14·732	·390	21·572	·571
1·30	·769	15·115	·383	22·133	·561

Table XI.—continued.

Number of volumes of expansion.	Corresponding density of products of combustion.	Total work that gunpowder is capable of performing.			
		Per kilogramme burned in metre tonnes.	Difference.	Per lb. burned in foot-tons.	Difference.
1·32	·758	15·875	·760	23·246	1·113
1·34	·746	16·611	·736	24·324	1·078
1·36	·735	17·326	·715	25·371	1·047
1·38	·725	18·021	·695	26·389	1·018
1·40	·714	18·698	·677	27·380	·991
1·42	·704	19·358	·660	28·348	·968
1·44	·694	20·002	·644	29·291	·943
1·46	·685	20·630	·628	30·211	·920
1·48	·676	21·243	·613	31·109	·898
1·50	·667	21·842	·599	31·986	·877
1·52	·658	22·427	·585	32·843	·857
1·54	·649	22·999	·572	33·681	·838
1·56	·641	23·558	·559	34·500	·819
1·58	·633	24·105	·547	35·301	·801
1·60	·625	24·641	·536	36·086	·785
1·62	·617	25·166	·525	36·855	·769
1·64	·610	25·680	·514	37·608	·753
1·66	·602	26·184	·504	38·346	·738
1·68	·595	26·678	·494	39·069	·723
1·70	·588	27·162	·484	39·778	·709
1·72	·581	27·637	·475	40·474	·696
1·74	·575	28·103	·466	41·156	·682
1·76	·568	28·561	·458	41·827	·671
1·78	·562	29·011	·450	42·486	·659
1·80	·555	29·453	·442	43·133	·647
1·82	·549	29·887	·434	43·769	·636
1·84	·543	30·314	·427	44·394	·625
1·86	·537	30·734	·420	45·009	·615
1·88	·532	31·147	·413	45·614	·605
1·90	·526	31·553	·406	46·209	·595
1·92	·521	31·953	·400	46·795	·586
1·94	·515	32·347	·394	47·372	·577
1·96	·510	32·735	·388	47·940	·568
1·98	·505	33·117	·382	48·499	·559
2·00	·500	33·493	·376	49·050	·551
2·05	·488	34·403	·910	50·383	1·333
2·10	·476	35·284	·881	51·673	1·290
2·15	·465	36·137	·853	52·922	1·249
2·20	·454	36·963	·826	54·132	1·210
2·25	·444	37·763	·800	55·304	1·172
2·30	·435	38·538	·775	56·439	1·135
2·35	·425	39·289	·751	57·539	1·100
2·40	·417	40·017	·728	58·605	1·066
2·45	·408	40·723	·706	59·639	1·034
2·50	·400	41·408	·685	60·642	1·003
2·55	·392	42·073	·665	61·616	·974
2·60	·384	42·720	·647	62·563	·947
2·65	·377	43·350	·630	63·486	·923
2·70	·370	43·964	·614	64·385	·899
2·75	·363	44·563	·599	65·262	·877
2·80	·357	45·148	·585	66·119	·857
2·85	·351	45·719	·571	66·955	·836
2·90	·345	46·276	·557	67·771	·816

TABLE XI.—continued.

Number of volumes of expansion.	Corresponding density of products of combustion.	Total work that gunpowder is capable of performing.			
		Per kilogramme burned in metre tonnes.	Difference.	Per lb. burned in foot-tons.	Difference.
2·95	·339	46·820	·544	68·568	·797
3·00	·333	47·352	·532	69·347	·779
3·05	·328	47·872	·520	70·109	·762
3·10	·322	48·381	·509	70·854	·745
3·15	·317	48·880	·499	71·585	·731
3·20	·312	49·369	·489	72·301	·716
3·25	·308	49·848	·479	73·002	·701
3·30	·303	50·318	·470	73·690	·688
3·35	·298	50·779	·461	74·365	·675
3·40	·294	51·231	·452	75·027	·662
3·45	·290	51·675	·444	75·677	·650
3·50	·286	52·111	·436	76·315	·638
3·55	·282	52·539	·428	76·940	·625
3·60	·278	52·959	·420	77·553	·613
3·65	·274	53·371	·412	78·156	·603
3·70	·270	53·776	·405	78·749	·593
3·75	·266	54·174	·398	79·332	·583
3·80	·263	54·565	·391	79·905	·573
3·85	·260	54·950	·385	80·469	·564
3·90	·256	55·329	·379	81·024	·555
3·95	·253	55·702	·373	81·570	·546
4·00	·250	56·069	·367	82·107	·537
4·10	·244	56·786	·717	83·157	1·050
4·20	·238	57·482	·696	84·176	1·019
4·30	·232	58·158	·676	85·166	·990
4·40	·227	58·815	·657	86·128	·962
4·50	·222	59·454	·639	87·064	·936
4·60	·217	60·076	·622	87·975	·911
4·70	·213	60·671	·605	88·861	·886
4·80	·208	61·260	·589	89·724	·863
4·90	·204	61·834	·574	90·565	·841
5·00	·200	62·394	·560	91·385	·820
5·10	·196	62·941	·547	92·186	·801
5·20	·192	63·475	·534	92·968	·782
5·30	·188	63·997	·522	93·732	·764
5·40	·185	64·507	·510	94·479	·747
5·50	·182	65·006	·499	95·210	·731
5·60	·178	65·494	·488	95·925	·715
5·70	·175	65·972	·478	96·625	·700
5·80	·172	66·440	·468	97·310	·685
5·90	·169	66·898	·458	97·981	·671
6·00	·166	67·347	·449	98·638	·657
6·10	·164	67·787	·440	99·282	·644
6·20	·161	68·219	·432	99·915	·633
6·30	·159	68·643	·424	100·536	·621
6·40	·156	69·059	·416	101·145	·609
6·50	·154	69·468	·409	101·744	·599
6·60	·151	69·870	·402	102·333	·589
6·70	·149	70·265	·395	102·912	·579
6·80	·147	70·653	·388	103·480	·568
6·90	·145	71·034	·381	104·038	·558
7·00	·143	71·411	·374	104·586	·548
7·10	·141	71·779	·368	105·125	·539

TABLE XI.—concluded.

Number of volumes of expansion.	Corresponding density of products of combustion.	Total work that gunpowder is capable of performing.			
		Per kilogramme burned in metre tonnes.	Difference.	Per lb. burned in foot-tons.	Difference.
7·20	·139	72·141	·362	105·655	·530
7·30	·137	72·497	·356	106·176	·521
7·40	·135	72·847	·350	106·688	·512
7·50	·133	73·191	·344	107·192	·504
7·60	·131	73·530	·339	107·688	·496
7·70	·130	73·864	·334	108·177	·489
7·80	·128	74·193	·329	108·659	·482
7·90	·126	74·517	·324	109·133	·474
8·00	·125	74·836	·319	109·600	·467
8·10	·123	75·150	·314	110·060	·460
8·20	·122	75·460	·310	110·514	·454
8·30	·120	75·766	·306	110·962	·448
8·40	·119	76·068	·302	111·404	·442
8·50	·117	76·366	·298	111·840	·436
8·60	·116	76·660	·294	112·270	·430
8·70	·115	76·950	·290	112·695	·425
8·80	·114	77·236	·286	113·114	·419
8·90	·112	77·519	·283	113·528	·414
9·00	·111	77·798	·279	113·937	·409
9·10	·110	78·074	·276	114·341	·404
9·20	·109	78·346	·272	114·739	·398
9·30	·108	78·615	·269	115·133	·394
9·40	·106	78·880	·265	115·521	·388
9·50	·105	79·142	·262	115·905	·384
9·60	·104	79·401	·259	116·284	·379
9·70	·103	79·657	·256	116·659	·375
9·80	·102	79·910	·253	117·029	·370
9·90	·101	80·160	·250	117·395	·366
10	·100	80·407	·247	117·757	·362
11	·091	82·734	2·327	121·165	3·408
12	·083	84·833	2·099	124·239	3·074
13	·077	86·743	1·910	127·036	2·797
14	·071	88·945	1·752	129·602	2·566
15	·066	90·112	1·617	131·970	2·368
16	·062	91·613	1·501	134·168	2·198
17	·059	93·013	1·400	136·218	2·050
18	·055	94·324	1·311	138·138	1·920
19	·052	95·557	1·233	139·944	1·806
20	·050	96·720	1·163	141·647	1·703
21	·047	97·820	1·100	143·258	1·611
22	·045	98·865	1·045	144·788	1·530
23	·043	99·858	·993	146·242	1·454
24	·042	100·805	·947	147·629	1·387
25	·040	101·709	·904	148·953	1·324
30	·033	105·701	3·992	154·800	5·847
35	·028	109·024	3·323	159·667	4·867
40	·025	111·865	2·841	163·828	4·161
45	·022	114·342	2·477	167·456	3·628
50	·020	116·537	2·195	170·671	3·215

Thus if we wished to know the maximum work of a given charge fired in a gun with such capacity of bore that the charge suffered five expansions during the motion of the projectile in the gun, the gravimetric density of the charge being unity, the table shows us that for every pound or kilogramme in the charge, an energy of 91·4 foot-tons or 62,394 kilogrammetres will as a maximum be generated.

If the factor of effect for the powder be known, the above values multiplied by that factor will give the energy per pound or kilogramme that may be expected to be raised in the projectile.

But it rarely happens, especially with the very large charges used in the most recent guns, that gravimetric densities so high as unity are employed, and in such cases, from the total realisable energy must be deducted the energy which the powder would have generated had it expanded from a density of unity to that actually occupied by the charge.

Thus in the instance above given, if we suppose the charge instead of a gravimetric density of unity to have a gravimetric density of ·8, which corresponds to a volume of expansion of 1·25, we see from Table XI. that from the 91·4 foot-tons or 62,394 kilogrammetres above given there must be subtracted* 19·23 foot-tons, or 13,127·3 kilogrammetres, leaving 72·17 foot-tons or 49,272·8 kilogrammetres as the maximum energy realisable under the given conditions per pound or per kilogramme of the charge.

As before, these values must be multiplied by the factor of effect to obtain the energy realisable in the projectile.

But to apply these principles to an actual case. The factor of effect of a certain brand of pebble powder having been found in a powder-proof gun to be with that gun between ·82 and ·84, let us examine what are the energies likely to be realised with charges of 70·90 and 100 lb. in an 8-inch gun, of 130 and 140 lb. in a 10-inch gun, and of 235 lb. in an 11-inch gun.

We have selected these instances both because the same powder was used in the experiments, and because they offer considerable variety with respect to the number of expansions and the gravimetric densities of the charges.

Taking first the 8-inch gun. The number of expansions that the charges experienced in the bore of the gun and the original gravimetric densities of the charges were as follow :—

For a charge of 70 lb., number of expansions 6·12, gravimetric density ·605
,, ,, 90 ,, ,, ,, 4·76 ,, ,, ·780
,, ,, 100 ,, ,, ,, 4·29 ,, ,, ·865

Hence from Table XI. the maximum energy realisable is

For the 70 lb. charge, 99·4 foot-tons —37·60 foot-tons =61·80 foot-tons per lb.
,, 90 ,, ,, 89·3 ,, —20·86 ,, =68·44 ,, ,,
,, 100 ,, ,, 84·9 ,, —13·66 ,, =71·24 ,, ,,

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* This correction, as has been elsewhere pointed out by one of us, is only approximate.

Multiplying these energies by the factors of effect obtained from the proof of the powder and by the number of pounds in the charge, we should expect the energy realised from the

70 lb. charge to lie between 3547·3 and 3633·8 foot-tons
90 „ „ „ „ 5050·9 „ 5174·0 „
100 „ „ „ „ 5841·7 „ 5984·2 „

Compare now these results with the actual experiments. On firing the above charges it was found that the 70 lb. charge gave to an 180 lb. shot a velocity of 1694 feet per second, corresponding to a total energy of 3637 foot-tons, the 90 lb. charge a velocity of 2027 feet per second, or a total energy of 5133 foot-tons, and the 100 lb. charge a velocity of 2182 feet per second, or an energy of 5940 foot-tons.

In the 10-inch gun the number of expansions and the gravimetric densities were

For the charge of 130 lb., number of expansions 4·294, gravimetric density 0·792
„ „ 140 „ „ „ 4·050 „ „ 0·840

Hence, as before, the maximum energies realisable are found to be

For the 130 lb., 65·14 foot-tons per lb. (84·94—19·80)
„ 140 „ 66·84 „ „ „ (82·50—15·66)

and multiplying by the same factors of effect, the total energy realised would lie between 6943·9 and 7113·3 foot-tons for the former, and between 7673·2 and 7860·4 foot-tons for the latter charge.

The actual results obtained with the 10-inch gun were for the 130 lb. charge a velocity of 1605 feet per second and an energy of 7158 foot-tons; for the 140 lb. charge a velocity of 1706 feet per second and an energy of 8092 foot-tons. With the 235 lb. charge fired from the 11-inch gun the number of expansions was 4·214, the gravimetric density of the charge ·770, while the energy realised was found to be 13,066 foot-tons, or 55·6 foot-tons per pound of powder used.

It will be noted that with the 8-inch gun (it happens that this calibre is the same as that of the gun used for powder proof, although the charges employed with this last are from one-half to one-third of those we are now discussing) the results realised are in each case very close to those predicted; ·84 as a factor of effect gives calculated results all but coincident with the high limit above given, but it must not be expected that results so closely accordant can always be obtained. Even when the same charges of the same powder and under precisely the same conditions are fired, considerable variations in energy sometimes have place. In the 10-inch gun, and with the larger charges of 130 and 140 lb., it will be observed that the realised energies are in both instances higher than the highest expected energy above given. In other words, for this gun and these charges a factor of from ·85 to ·86 should be used instead of the factor ·84. Again, with the 11-inch gun, when the still larger charge of 235 lb. was employed, it will be found from the figures above given that the factor of effect for this gun, powder, and charge is about ·89.

Hence the factor of effect with the same powder has gradually increased from about ·83 in the powder-proof gun, to ·84 in the 8-inch gun, to ·86 in the 10-inch, and to ·89 in the 11-inch gun. And generally we must point out that not only may the factors of effect differ very much with the powders employed, being in this respect dependent upon circumstances, such as the density of the powder, its size of grain, amount of moisture, chemical composition, nature of charcoal used, &c., but they may also vary considerably even with the same powder if the charges be not fired under precisely the same circumstances. For example, especially with slow-burning powders, the weight of the shot fired exerts a very material influence upon the factor of effect, and the reason is obvious: the slower the shot moves at first the earlier in its passage up the bore is the charge entirely consumed and the higher is the energy realised. The same effect, unless modified by other circumstances, is produced when the charge is increased with the same weight of projectile. In this case the projectile has to traverse a greater length of bore before the same relief due to expansion is attained. The higher pressures which consequently rule react upon the rate of combustion of the powder, and again a somewhat higher energy is obtained.

But these increased effects, of course, correspond to an increased initial tension of the powder gases; but, especially with the smaller guns, a very great difference in the realised energy may arise from other causes. Thus, it having been found that with certain breechloading guns a superior effect was attained by substituting copper rings for lead coating, it was assumed that the cause of this superiority was due to the less friction of the copper rings in the passage of the shot up the bore. But it occurred to one of us that the superior effect was in all probability not due to less friction, and the following experiments were made.

Three rounds were fired from a 12-centimetre B. L. gun with 7 lb. R. L. G. powder and the ordinary service lead-coated shot. The energy realised per lb. of powder was 80·65 foot-tons.

Three more rounds were fired with the lead considerably reduced, and so as barely to fill the grooves. The mean energy realised per lb. was 78·68 foot-tons, thus showing that no superior effect was thereby obtained.

Two rounds were then fired with shell fitted with copper rings. The energy obtained was 82 foot-tons per lb. and the gain was real, but the chamber pressure ran up from a mean of 16·8 tons on the square inch to a mean of 18·6 tons, thus showing that, at all events in great measure, the increased effect is caused not by the copper bands giving rise to less loss by friction, but to the fact that the increased difficulty of forcing the copper bands into the grooves permits the powder to become fully burned at an earlier point in the bore, and thus an increased effect from the powder is realised.

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

Two rounds, one with each form of gas-check, were then fired with a charge of 7 lb. of R. L. G. powder, every condition, except as noted, being precisely the same; the velocities with the two forms were respectively 1609 feet per second and 1512 feet per second, giving rise to 82·04 and 72·44 foot-tons per lb. of powder. The chamber pressures were respectively 15·2 and 12·0[*] tons per square inch. Two further rounds were then fired with charges of 7½ lb. R. L. G., when velocities of 1644 and 1544 feet per second, or energies per lb. of 79·94 and 70·51 foot-tons were respectively obtained, the chamber pressures in this case being 16·4 and 14·1 tons per square inch.

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

In cases where the projectile has been removed for a considerable distance from the charge, that is, when there is a considerable air space between the charge and the projectile, it has been found that the energy developed in the projectile is materially higher than that due to the expansion of the powder gases through the space traversed by the projectile, and the cause of this appears to us clear. When the charge is ignited at one end of the bore and the ignited products have to travel a considerable distance before striking the projectile, these ignited products possess considerable energy, and a portion of this energy will be communicated to the projectile by direct impact.

With the great lengths of charges used in the larger guns of the present day, some action of this sort doubtless, under ordinary circumstances, frequently happens, thus giving rise to somewhat more energy in the projectile than that due to the expansion of the gases from their initial density in the powder chamber to their final density when the projectile reaches the muzzle of the gun.[†]

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[*] The figures given denote the pressures on the bottom of the chamber and the base of the projectile respectively. The pressures are given as observed, but that on the base of the projectile requires an addition not generally made in actual practice.

[†] As bearing upon the energy which is usually assigned to a projectile, we may remark that it is customary in correcting the measured to the muzzle velocity to assume that the loss due to the resistance of the air has accrued from the instant the shot quitted the muzzle. But, especially with the large charges and high-muzzle pressures now employed, we believe this rule should be greatly modified.

For a considerable distance from the muzzle of the gun the projectile will be moving in an atmosphere

A considerable number of rounds have been fired from small guns with mining powder. The particular powder of which the analysis is given in this memoir generated an energy differing but little from those obtained with R. L. G. under like conditions. Another sample of mining powder, however, differing from the first sample in containing a higher proportion of saltpetre, generated an energy higher than did any of the R. L. G. powders with which it was compared. This last powder, we may remark, was that which gave the pressure of 44 tons on the square inch when fired in an absolutely close vessel with a gravimetric density of unity.

The Spanish spherical pellet powder generated rather less energy than did the mining powder, but in neither powder did the realised effect vary more from that generated by the normal service Waltham Abbey powders than do occasional samples of these last—a sufficiently curious result, as we have already remarked, when the differences in the composition and the great differences in the decomposition of the various powders are taken into account.

The same remarks as to energy apply generally to the small-grained powders.

These, indeed, cannot be fired satisfactorily without special arrangements in very large charges, chiefly, among other reasons, from their tendency to cake under the pressure of the first ignited portion; but for smaller charges the tables in this memoir alike apply.

Of course, were similar weights of pebble, R. L. G., and F. G. fired in the same gun, the gun being supposed to be of small calibre, the energy realised by the F. G. would be greater than that realised by R. L. G., and still greater than that realised by pebble, on account of its much more rapid combustion. The maximum pressures developed in the bore would correspond with the energies realised.

When the maximum chamber pressure as well as the energy developed by a given charge in a given gun are known, we are able from Table X. to fix very approximately the position of the shot in the bore when the combustion of the charge may practically be considered to be effected. Thus, if with a given energy in the projectile it is found that the maximum chamber pressure is 3118 atmospheres (20·46 tons on the square inch), we learn from Table X. that this tension corresponds to a density of the products of combustion of ·70; and hence the charge may be supposed to be practically consumed when the projectile is in such a position in the bore that the products have this mean density. Again, if the observed pressure was 2400 atmospheres (15·73 tons per square inch), the same table shows us that, when this pressure is reached, the position of the projectile in the bore corresponds to a density of charge of ·60.

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with a velocity higher than its own, and for some short distance it appears to us probable that its velocity may be receiving an appreciable increase. As corroborative of our views, we may note the great indications of pressure upon gas-checks on the projectiles after these last are released from the support of the bore. Also the fact that when muzzle velocities calculated from data measured inside the bore were compared with those calculated from data measured outside, the latter were in all cases somewhat higher.

It will be gathered from what has just been said that, with a little experience, if the factor of effect and maximum chamber pressure in any gun be known, the behaviour of the same powder in other guns, or in the same gun with other charges or weights of shot, can be anticipated. It was the consideration of the results embodied in Tables X. and XI. that allowed the high energies (more than twice as great as those obtained from the same calibres a few years back) to be predicted and realised; to be realised, also, with less strain to the gun than when much smaller charges were fired, without attention being paid to the all-important point of the density of the products of explosion at the moment when such explosion may be considered to be completed.

It will readily be understood from our remarks upon Table XI. that, to the artillerist, two descriptions of factors of effect are useful. One of these factors is employed to give the ratio between the work actually realised in a given gun, and the maximum work attainable by the charge (its gravimetric density being supposed to be unity). The value of this factor shows whether or not the charge is economically employed. The other factor is employed to denote the ratio between the work actually realised and the maximum work realisable by the charge, in expanding from the gravimetric density of the powder chamber to the mean density of the products of explosion, at the moment when the projectile leaves the muzzle of the gun.

With respect to the first class of factors, it would obviously be difficult to lay down general rules. The value of the factor depends mainly upon the gravimetric density of the charge, but we may remark that, in the most modern guns, even with the advantage they possess of great absolute length, the powder is very uneconomically burned. With the very high charges and consequent small number of expansions, with the low gravimetric density also of the charge, the realised energy per pound of powder is necessarily much lower than was the case with the older guns.

The same difficulty does not exist with regard to the second class of factors of effect. With respect to these, it may be enough to state that, in the smaller guns with R. L. G. powder, the factors of effect vary with a mild brand of powder from ·71 to ·76; with a specially violent brand, from ·82 to ·89, the variations being chiefly dependent upon the principles we have already explained.

In 6-inch guns, firing pebble powder of the normal quality, the factors of effect vary from ·75 to ·82; and, as the calibres of the guns are increased, the factors of effect likewise gradually increase, until, in the 80 and 100-ton guns, factors of from ·89 to ·96 have usually been reached.

In concluding this memoir we desire to remark that, although the agreement between the results of the long and laborious series of experiments and calculations which we now bring to a close have far exceeded the expectations we had formed when we commenced our task, it would yet be idle to suppose that many of our deductions, referring as they do to temperatures and tensions far above the range of ordinary research, will not require some subsequent correction.

But although certain minor points may, as we have said, require considerable correction, we have little doubt that the main theories upon which we insist—confirmed, as they are, by experiments made or facts obtained under an almost infinite variety of circumstances—must be accepted as very approximately correct. It is satisfactory to find that the laws which rule the tensions and temperatures of gases under ordinary circumstances do not lose their physical significance, but are still approximately applicable at the high temperatures and pressures we have been considering.

At all events, whether we are right or wrong in taking this view, it appears to us certain that the rules and tables we have laid down, based on our analyses, experiments, and calculations, may for all practical purposes be accepted as correct, and may, bearing in mind the restrictions to which we have referred in this memoir, be applied to nearly every question of internal ballistics.

Memorandum showing the elementary substances found in the products of explosion, and existing in the powder before combustion.

EXPERIMENT 8.—102·77 grms. pebble, density =·1.

	Calculated solid products. grms.	Calculated gaseous products. grms.
From analysis of solids . . .	56·950	45·820
" " gas	58·411	44·359
" " mean . . .	57·680	45·090

Elements in—	K.	C.	S.	H.	O.	N.	Remarks.
Gaseous state	. .	9·518	1·294	·153	22·298	11·827	
Solid state	30·039	2·803	7·227	·008	17·517	·086	
Total found	30·039	12·321	8·521	·161	39·815	11·913	
Originally in powder .	29·660	12·456	10·349	·534	38·720	12·160	
Difference	+·379	−·135	−1·828	—·373	+1·092	−·247	

Oxygen in hyposulphite, 3·013 grms.

Experiment 7.—204·117 grms. pebble, density =·2.

	Calculated solid products. grms.	Calculated gaseous products. grms.
From analysis of solids . . .	111·271	92·846
,, ,, gas	117·195	86·922
,, ,, mean . . .	114·233	89·884

Elements in—	K.	C.	S.	H.	O.	N.	Remarks.
Gaseous state	. .	19·06	3·53	·41	44·04	22·84	
Solid state	60·47	5·73	18·19	·01	29·74	·05	
Total found	60·47	24·79	21·72	·42	73·78	22·89	
Originally in powder .	58·91	24·74	20·56	1·06	76·58	23·01	
Difference	+1·56	+0·05	+1·16	−·64	−2·80	−0·12	

Oxygen in hyposulphite, 1·070 grms.

Experiment 9.—306·175 grms. pebble, density =·3.

	Calculated solid products. grms.	Calculated gaseous products. grms.
From analysis of solids . . .	167·338	138·837
,, ,, gas	174·011	132·164
,, ,, mean . . .	170·674	135·501

Elements in—	K.	C.	S.	H.	O.	N.	Remarks.
Gaseous state	. .	29·119	3·596	·442	67·927	34·417	
Solid state	90·126	8·904	26·166	·024	45·246	·208	
Total found	90·126	38·023	29·762	·466	113·173	34·625	
Originally in powder .	88·362	37·108	30·832	1·592	114·771	34·006	
Difference	−1·764	+0·915	−1·070	−1·126	−1·598	+0·619	

Oxygen in hyposulphite, 1·858 grms.

EXPERIMENT 12.—411·085 grms. pebble, density =·4.

	Calculated solid products. grms.	Calculated gaseous products. grms.
From analysis of solids . . .	237·717	173·368
,, ,, gas	230·767	180·318
,, ,, mean . . .	234·242	176·843

Elements in—	K.	C.	S.	H.	O.	N.	Remarks.
Gaseous state	. .	38·314	2·712	·466	90·344	45·007	
Solid state	116·983	11·342	39·047	·013	64·703	·262	
Total found	116·983	49·656	41·759	·479	155·047	45·269	
Originally in powder .	118·639	49·824	41·396	2·138	154·058	45·235	
Difference	−1·656	−0·168	+·363	−1·659	+·989	+·034	

Oxygen in hyposulphite, 8·311 grms.

EXPERIMENT 14.—513·856 grms. pebble, density =·5.

	Calculated solid products. grms.	Calculated gaseous products. grms.
From analysis of solids . . .	278·232	235·624
,, ,, gas	288·739	225·117
,, ,, mean . . .	283·485	230·370

Elements in—	K.	C.	S.	H.	O.	N.	Remarks.
Gaseous state	. .	49·715	4·073	·676	117·361	58·520	
Solid state	151·125	13·957	45·428	·018	72·595	·361	
Total found	151·125	63·672	49·501	·694	189·956	58·881	
Originally in powder .	148·299	62·279	51·745	2·672	192·505	56·244	
Difference	+2·826	+1·393	−2·244	−1·978	−2·549	+2·637	

Oxygen in hyposulphite, 4·372 grms.

EXPERIMENT 37.—295·488 grms. pebble, density =·6.

	Calculated solid products. grms.	Calculated gaseous products. grms.
From analysis of solids . . .	167·161	128·327
,, ,, gas	166·076	129·412
,, ,, mean . . .	166·618	128·870

Elements in—	K.	C.	S.	H.	O.	N.	Remarks.
Gaseous state	. .	27·874	2·608	·398	65·580	32·410	
Solid state	85·001	8·424	26·806	·008	45·911	·468	
Total found	85·001	36·298	29·414	·406	111·491	32·878	
Originally in powder .	85·277	35·813	29·756	1·536	110·672	32·254	
Difference	−0·276	+0·485	−0·342	−1·130	+0·819	+0·624	

Oxygen in hyposulphite, 4·178 grms.

EXPERIMENT 38.—344·736 grms. pebble, density =·70.

	Calculated solid products. grms.	Calculated gaseous products. grms.
From analysis of solids . . .	202·460	142·276
,, ,, gas	192·885	151·851
,, ,, mean . . .	197·673	147·063

Elements in—	K.	C.	S.	H.	O.	N.	Remarks.
Gaseous state	. .	31·133	4·193	·484	74·178	37·075	
Solid state	97·174	8·742	31·291	·009	60·143	·314	
Total found	97·174	39·875	35·484	·493	134·321	37·389	
Originally in powder .	99·491	41·782	34·715	1·793	129·060	37·413	
Difference	−·317	−1·907	+·709	−1·300	+5·261	−·024	

Oxygen in hyposulphite, 16·030 grms.

EXPERIMENT 43 (76).—393·984 grms. pebble, density = ·8.

	Calculated solid products. grms.	Calculated gaseous products. grms.
From analysis of solids . . .	229·932	164·052
,, ,, gas	219·181	174·803
,, ,, mean . . .	224·557	169·427

Elements in—	K.	C.	S.	H.	O.	N.	Remarks.
Gaseous state	. .	36·157	2·965	·402	86·801	43·102	
Solid state	111·046	11·647	34·704	·015	66·653	·490	
Total found	111·046	47·804	37·669	·417	153·454	43·592	
Originally in powder .	113·704	47·751	39·674	2·049	147·519	42·801	
Difference	−2·658	+·053	−2·005	−1·632	+5·935	+·791	

Oxygen in hyposulphite, 11·708 grms.

EXPERIMENT 77.—417·31 grms. pebble, density = ·9.

	Calculated solid products. grms.	Calculated gaseous products. grms.
From analysis of solids . . .	246·150	171·160
,, ,, gas	232·380	184·930
,, ,, mean . . .	239·260	178·050

Elements in—	K.	C.	S.	H.	O.	N.	Remarks.
Gaseous state	. .	37·765	3·385	·547	90·866	45·492	
Solid state	117·064	13·570	37·799	·023	70·127	·676	
Total found	117·064	51·335	41·184	·570	160·993	46·168	
Originally in powder .	120·436	50·578	42·023	2·170	156·237	45·306	
Difference	−3·372	+·757	−·839	−1·600	+4·756	+·862	

Oxygen in hyposulphite, 8·001 grms.

EXPERIMENT 1.—90·719 grms. R. L. G., density =·1.

	Calculated solid products. grms.	Calculated gaseous products. grms.
From analysis of solids . . .	52·256	38·463
" " gas	51·565	39·154
" " mean . . .	51·910	38·809

Elements in—	K.	C.	S.	H.	O.	N.	Remarks.
Gaseous state	. .	7·648	1·421	·149	18·698	10·894	
Solid state	26·113	2·747	6·774	·003	16·222	·051	
Total found	26·113	10·395	8·195	·152	34·920	10·945	1st analysis of powder top of barrel.
Originally in powder .	26·299	9·852	9·344	·490	34·698	11·149	
Difference	−·186	+·543	−1·149	−·338	+·222	−·204	

Oxygen in hyposulphite, 2·665 grms.

EXPERIMENT 3.—190·538 grms. R. L. G., density =·2.

	Calculated solid products. grms.	Calculated gaseous products. grms.
From analysis of solids . . .	108·556	81·982
" " gas	109·503	81·035
" " mean . . .	109·030	81·508

Elements in—	K.	C.	S.	H.	O.	N.	Remarks.
Gaseous state	. .	16·256	2·669	·289	39·397	22·896	
Solid state	55·479	5·222	16·191	·005	32·037	·100	1st analysis.
Total found	55·479	21·478	18·860	·294	71·434	22·996	
Originally in powder .	55·237	20·692	19·625	1·029	72·559	22·169	
Difference	+·242	+·786	−·765	−·735	−1·125	+·827	

Oxygen in hyposulphite, 1·580 grms.

EXPERIMENT 4.—285·833 grms. R. L. G., density =·3.

	Calculated solid products. grms.	Calculated gaseous products. grms.
From analysis of solids . . .	165·992	119·841
„ „ gas	163·174	122·659
„ „ mean . . .	164·583	121·250

Elements in—	K.	C.	S.	H.	O.	N.	Remarks.
Gaseous state	. .	25·142	3·423	·421	60·582	31·683	
Solid state	82·167	7·521	24·770	·005	50·068	·053	1st analysis.
Total found	82·167	32·663	28·193	·426	110·650	31·736	
Originally in powder .	82·863	31·041	29·441	1·543	108·674	32·756	
Difference	−·696	+1·622	−1·248	−1·117	+1·976	−1·020	

Oxygen in hyposulphite, 5·330 grms.

EXPERIMENT 11.—381·091 grms. R. L. G., density =·4.

	Calculated solid products. grms.	Calculated gaseous products. grms.
From analysis of solids . . .	224·951	156·140
„ „ gas	216·358	164·753
„ „ mean . . .	220·655	160·436

Elements in—	K.	C.	S.	H.	O.	N.	Remarks.
Gaseous state	. .	33·338	2·793	·451	80·520	43·334	
Solid state	108·521	9·400	33·047	·007	69·500	·180	1st analysis.
Total found	108·521	42·738	35·840	·458	150·020	43·514	
Originally in powder .	110·478	41·386	39·252	2·058	144·859	43·278	
Difference	−1·957	+1·352	−3·412	−1·600	+5·161	+·236	

Oxygen in hyposulphite, 13·379 grms.

Experiment 70.—246·286 grms. R. L. G., density =·5.

	Calculated solid products. grms.	Calculated gaseous products. grms.
From analysis of solids . . .	143·997	102·289
„ „ gas	141·824	104·462
„ „ mean . . .	142·910	103·376

Elements in—	K.	C.	S.	H.	O.	N.	Remarks.
Gaseous state	. .	23·215	1·537	·373	53·089	25·162	
Solid state	70·862	7·610	22·013	·011	42·133	·281	
Total found	70·862	30·825	23·550	·384	95·222	25·443	
Originally in powder .	70·906	30·535	24·917	1·278	90·768	27·873	
Difference	−·044	+·290	−1·367	− 894	+4·454	−2·430	

Oxygen in hyposulphite, 9·122 grms.

Experiment 39.—295·483 grms. R. L. G., density =·6.

	Calculated solid products. grms.	Calculated gaseous products. grms.
From analysis of solids . . .	167·871	127·612
„ „ gas	168·697	126·786
„ „ mean . . .	168·284	127·199

Elements in—	K.	C.	S.	H.	O.	N.	Remarks.
Gaseous state	. .	27·734	1·856	·020	65·477	31·812	N.B.—2nd analysis taken.
Solid state	85·451	9·421	26·182	·015	47·016	·199	
Total found	85·451	37·155	28·038	·335	112·493	32·011	
Originally in powder .	85·070	36·634	29·894	1·534	108·131	32·766	
Difference	+·381	+·521	−1·856	−1·199	+4·362	−·755	

Oxygen in hyposulphite, 2·748 grms.

EXPERIMENT 96.—295·488 grms. R. L. G., density =·6.

	Calculated solid products. grms.	Calculated gaseous products. grms.
From analysis of solids . . .	169·403	126·085
„ „ gas	169·256	126·232
„ „ mean . . .	169·330	126·158

Elements in—	K.	C.	S.	H.	O.	N.	Remarks.
Gaseous state	. .	26·454	4·938	·511	61·681	32·574	
Solid state	85·031	9·694	25·771	·012	48·514	·308	2nd analysis.
Total found	85·031	36·148	30·709	·523	110·195	32·882	
Originally in powder .	85·071	36·635	29·895	1·534	108·870	33·250	
Difference	−·040	−·487	+·814	−1·011	+1·325	−·368	

Oxygen in hyposulphite, 2·940 grms.

EXPERIMENT 41.—344·736 grms. R. L. G., density =·7.

	Calculated solid products. grms.	Calculated gaseous products. grms.
From analysis of solids . . .	201·915	142·821
„ „ gas	194·931	149·805
„ „ mean . . .	198·423	146·313

Elements in—	K.	C.	S.	H.	O.	N.	Remarks.
Gaseous state	. .	31·195	3·745	·642	74·051	36·681	
Solid state	98·211	10·545	30·085	·013	59·083	·486	2nd analysis.
Total found	98·211	41·740	33·830	·655	133·134	37·167	
Originally in powder .	99·249	42·740	34·877	1·787	126·987	38·803	
Difference	−1·038	−1·000	−1·047	−1·132	+6·147	−1·636	

Oxygen in hyposulphite, 9·300 grms.

EXPERIMENT 44.—393·978 grms. R. L. G., density =·8.

	Calculated solid products. grms.	Calculated gaseous products. grms.
From analysis of solids . . .	221·009	172·969
,, ,, gas	231·376	162·602
,, ,, mean . . .	226·192	167·785

Elements in—	K.	C.	S.	H.	O.	N.	Remarks.
Gaseous state	. .	36·327	2·338	·452	86·473	42·195	
Solid state	111·655	13·185	39·264	·021	61·613	·452	2nd analysis.
Total found	111·655	49·512	41·602	·473	148·086	42·647	
Originally in powder .	113·426	48·845	39·859	2·045	145·103	42·987	
Difference	−1·771	+·667	+1·743	−1·572	+2·983	−·340	

Oxygen in hyposulphite, 1·761 grms.

EXPERIMENT 68.—443·23 grms. R. L. G., density =·9.

	Calculated solid products. grms.	Calculated gaseous products. grms.
From analysis of solids . . .	257·858	185·372
,, ,, gas	248·696	194·534
,, ,, mean . . .	253·277	189·953

Elements in—	K.	C.	S.	H.	O.	N.	Remarks.
Gaseous state	. .	40·551	3·199	·500	97·626	48·077	
Solid state	126·402	14·635	40·142	·031	71·412	·643	2nd analysis.
Total found	126·402	55·186	43·341	·531	169·038	48·720	
Originally in powder .	127·606	54·952	44·842	2·300	163·233	49·735	
Difference	−1·204	+·234	−1·501	−1·769	+5·805	−1·015	

Oxygen in hyposulphite, 5·490 grms.

EXPERIMENT 16.—102·771 grms. F. G., density =·10.

	Calculated solid products. grms.	Calculated gaseous products. grms.
From analysis of solids . . .	55·762	47·009
,, ,, gas	61·736	41·038
,, ,, mean . . .	58·749	44·022

Elements in—	K.	C.	S.	H.	O.	N.	Remarks.
Gaseous state	. .	9·436	0·928	·164	21·784	11·710	
Solid state	30·905	2·524	7·721	·003	18·028	·068	
Total found	30·905	11·960	8 149	·167	39·812	11·778	
Originally in powder .	29·331	11·675	10·380	·668	39 795	11·927	
Difference	+1·574	+·285	−2·231	−·501	+·017	−·149	

Oxygen in hyposulphite, 3·518 grms.

EXPERIMENT 17.—205·542 grms. F. G., density =·2.

	Calculated solid products. grms.	Calculated gaseous products. grms.
From analysis of solids . . .	116·719	88·823
,, ,, gas	122·390	83·152
,, ,, mean . . .	119·554	85·987

Elements in—	K.	C.	S.	H.	O.	N.	Remarks.
Gaseous state	. .	17·770	2·977	·393	42·430	22·417	
Solid state	60·080	6·202	16·091	·015	37·099	·068	
Total found	60·080	23·972	19·068	·408	79·527	22·485	
Originally in powder .	58·662	23·349	20·760	1·336	79·281	23·055	
Difference	+1·413	+·623	−1·692	−·928	+·246	−·570	

Oxygen in hyposulphite, 1·597 grms.

EXPERIMENT 18.—308·32 grms. F. G., density = ·3.

	Calculated solid products. grms.	Calculated gaseous products. grms.
From analysis of solids . . .	177·44	130·88
,, ,, gas	181·80	126·52
,, ,, mean . . .	179·62	128·70

Elements in—	K.	C.	S.	H.	O.	N.	Remarks.
Gaseous state	. .	27·055	2·579	·419	65·764	32·883	
Solid state	89·076	7·219	26·863	·002	56·388	·072	
Total found	89·076	34·274	29·442	·421	122·152	32·955	
Originally in powder .	89·994	35·025	31·140	2·004	118·750	33·088	
Difference	—·918	—·751	—1·698	—1·583	+3·402	—·133	

Oxygen in hyposulphite, 12·484 grms.

EXPERIMENT 19.—411·085 grms. F. G., density = ·4.

	Calculated solid products. grms.	Calculated gaseous products. grms.
From analysis of solids . . .	237·880	173·210
,, ,, gas	240·970	170·116
,, ,, mean . . .	239·430	171·660

Elements in—	K.	C.	S.	H.	O.	N.	Remarks.
Gaseous state	. .	36·039	3·086	·519	88·006	44·015	
Solid state	118·118	9·382	37·849	·008	73·990	·086	
Total found	118·118	45·421	40·935	·527	161·996	44·101	
Originally in powder .	117·325	46·700	41·520	2·672	158·294	45·030	
Difference	+·793	—1·279	—·585	—2·145	+3·702	—·929	

Oxygen in hyposulphite, 17·262 grms.

Experiment 75.—246·286 grms. F. G., density =·5.

	Calculated solid products. grms.	Calculated gaseous products. grms.
From analysis of solids . . .	141·760	104·526
,, ,, gas	144·474	101·812
,, ,, mean . . .	143·117	103·169

Elements in—	K.	C.	S.	H.	O.	N.	Remarks.
Gaseous state	. .	21·526	2·049	·334	52·261	26·999	
Solid state	70·963	7·000	21·291	·009	43·768	·085	
Total found	70·963	28·526	23·340	·343	96·029	27·084	
Originally in powder .	70·290	27·978	24·875	1·601	94·805	26·849	
Difference	+·673	+·548	−1·535	−1·258	+1·224	+·235	

Oxygen in hyposulphite, 4·840 grms.

Experiment 40.—295·488 grms. F. G., density =·6.

	Calculated solid products. grms.	Calculated gaseous products. grms.
From analysis of solids . . .	170·268	125·220
,, ,, gas	172·509	122·979
,, ,, mean . . .	171·388	124·099

Elements in—	K.	C.	S.	H.	O.	N.	Remarks.
Gaseous state	. .	25·770	2·511	·368	63·097	32·353	
Solid state	84·762	6·281	26·233	·002	53·973	·137	
Total found	84·762	32·051	28·744	·370	117·070	32·490	
Originally in powder .	84·332	33·567	29·844	1·921	113·765	32·106	
Difference	+·430	−1·516	−1·100	−1·551	+3·305	+·384	

Oxygen in hyposulphite, 13·786 grms.

EXPERIMENT 42.—344·738 grms. F. G., density =·7.

	Calculated solid products. grms.	Calculated gaseous products. grms.
From analysis of solids . . .	200·191	144·547
,, ,, gas	200·220	144·520
,, ,, mean . . .	200·210	144·533

Elements in—	K.	C.	S.	H.	O.	N.	Remarks.
Gaseous state	. .	29·628	2·614	·413	73·372	38·503	
Solid state	98·540	7·474	30·531	·112	63·417	·135	
Total found	98·540	37·102	33·145	·525	136·789	38·638	
Originally in powder .	98·388	39·162	34·819	2·241	132·644	37·357	
Difference	+·152	−2·060	−1·674	−1·716	+4·145	+1·281	

Oxygen in hyposulphite, 16·182 grms.

EXPERIMENT 47.—393·987 grms. F. G., density =·8.

	Calculated solid products. grms.	Calculated gaseous products. grms.
From analysis of solids . . .	231·652	162·335
,, ,, gas	229·392	164·595
,, ,, mean . . .	230·522	163·465

Elements in—	K.	C.	S.	H.	O.	N.	Remarks.
Gaseous state	. .	33·138	3·800	·492	81·851	44·184	
Solid state	111·893	8·830	36·136	·008	73·363	·292	
Total found	111·893	41·968	39·936	·500	155·214	44·476	
Originally in powder .	112·444	44·757	39·793	2·561	151·572	42·614	
Difference	−·551	−2·789	+·143	−2·061	+3·642	+1·862	

Oxygen in hyposulphite, 20·106 grms.

EXPERIMENT 69.—443·230 grms. F. G., density =·90.

	Calculated solid products. grms.	Calculated gaseous products. grms.
From analysis of solids . . .	255·256	187·974
,, ,, gas	257·131	186·099
,, ,, mean . . .	256·193	187·037

Elements in—	K.	C.	S.	H.	O.	N.	Remarks.
Gaseous state	. .	38·027	4·875	·545	94·624	48·966	
Solid state	127·001	11·372	38·012	·006	79·476	·327	
Total found	127·001	49·399	42·887	·551	174·100	49·293	
Originally in powder .	126·495	50·350	44·765	2·881	170·498	47·878	
Difference	+·506	−·951	−1·878	−2·330	+3·602	+1·415	

Oxygen in hyposulphite, 16·702 grms.

EXPERIMENT 78.—344·738 grms. R. F. G., density =·7.

	Calculated solid products. grms.	Calculated gaseous products. grms.
From analysis of solids . . .	202·222	142·516
,, ,, gas	200·960	143·780
,, ,, mean . . .	201·591	143·148

Elements in—	K.	C.	S.	H.	O.	N.	Remarks.
Gaseous state	. .	29·469	2·048	·346	72·664	38·621	
Solid state	99·765	10·360	29·551	·008	61·834	·073	
Total found	99·765	39·829	31·599	·354	134·498	38·694	
Originally in powder .	100·077	36·784	34·336	2·103	134·747	36·323	
Difference	—·312	+3·045	−2·737	−1·749	—·250	+2·371	

Oxygen in hyposulphite, 4·140 grms.

Experiment 79.—344·738 grms. Spanish, density =·7.

	Calculated solid products. grms.	Calculated gaseous products. grms.
From analysis of solids . . .	214·917	129·821
„ „ gas	213·875	130·863
„ „ mean . . .	214·396	130·342

Elements in—	K.	C.	S.	H.	O.	N.	Remarks.
Gaseous state	. .	24·953	3·140	·288	64·032	37·930	
Solid state	100·418	6·545	38·338	·007	68·758	·330	
Total found	100·418	31·498	41·478	·295	132·790	38·260	
Originally in powder .	100·663	29·820	42·989	1·551	131·506	36·461	
Difference	−·245	+1·678	−1·511	−1·256	+1·284	+1·799	

Oxygen in hyposulphite, 4·106 grms.

Experiment 196.—301·315 grms. Curtis and Harvey's No. 6, density =·3.

	Calculated solid products. grms.	Calculated gaseous products. grms.
From analysis of solids . . .	168·827	128·963
„ „ gas	180·818	116·972
„ „ mean . . .	174·823	122·967

Elements in—	K.	C.	S.	H.	O.	N.	Remarks.
Gaseous state	. .	25·389	2·337	·725	60·639	33·877	
Solid state	90·017	8·918	24·324	·013	51·435	·116	
Total found	90·017	34·307	26·661	·738	112·074	33·993	
Originally in powder .	86·929	32·120	31·427	1·567	113·687	31·156	
Difference	+3·088	+2·187	−4·766	−·829	−1·613	+2·837	

Oxygen in hyposulphite, 1·731 grms.

EXPERIMENT 194.—301·315 grms. mining powder, density = ·3.

	Calculated solid products. grms.	Calculated gaseous products. grms.
From analysis of solids . . .	142·743	153·921
„ „ gas	143·895	152·569
„ „ mean . . .	143·319	153·145

Elements in—	K.	C.	S.	H.	O.	N.	Remarks.
Gaseous state	. .	39·601	10·909	1·714	75·330	25·591	
Solid state	70·596	11·801	35·901	·205	23·488	1·328	
Total found	70·596	51·402	46·810	1·919	98·818	26·919	
Originally in powder .	72·014	54·026	45·378	1·989	95·336	25·943	
Difference	−1·418	−2·624	+1·432	−·070	+3·482	+·976	

Oxygen in hyposulphite, 2·062 grms.

ABSTRACT OF EXPERIMENTS.

In this abstract the following abbreviations are used:—

δ, to represent the mean density of the products of explosion; A, the area of the piston of the crusher-gauge; a, the sectional area of the copper cylinder.

Experiment 96.—4560 grs. (295·49 grms.) R. L. G.; this experiment is No. 39 repeated. On opening cylinder appearances as usual—colour of fracture, a dark bluish grey; surface not smooth but wavy; tears remained adhering to the side, and the usual sooty deposit observed.

δ.	A.	a.	Crush.	Pressure.
·57	·0833	·0417	·134	14·32 tons per square inch.

Experiment 121.—Fired 5960 grs. (386·21 grms.) R. L. G. in large cylinder. Density ·4.

On opening, appearances much as usual. Fracture, slaty grey with yellowish portions. Divided deposit into two portions, top and bottom. Bottom decidedly more yellow than the top. Divided again top and bottom portions into two parts, one bottled and sealed with as little exposure to the air as possible, the other ground and freely exposed to the air for 48 hours.

The ground portion heated but slightly, the bottom portion showing this tendency in the highest degree, but the heating was on the whole very abnormally low.

During exposure the colour of the ground deposit became considerably lighter.

Experiment 122.—Fired 5960 grs. (386·21 grms.) pebble in large cylinder. Density ·4.

On opening the cylinder observed that the deposit was lighter in colour than in the case of the R. L. G. The fracture was also different, being lighter and having several isolated portions yellow or greenish yellow.

Divided, as in last experiment, the deposit into top and bottom, a portion of each being bottled with as little exposure as possible, and a portion of each being finely ground and exposed to the atmosphere for about 48 hours.

The bottom part of the deposit was lighter and yellower than the top portion.

The top ground deposit began to heat when placed on the paper, the deposit on the apex and in the interior, where the greatest heat prevailed, changing rapidly to a light sulphury yellow with a tinge of green.

It attained its greatest heat in about 10 minutes, and in about 15 minutes later was not *hot* to the hand.

The bottom ground portion exhibited the tendency to heat in a much higher degree than the top portion, commencing to heat immediately; the colour of the residue darkening while an orange coloured deposit formed on the surface.

During the exhibition of heat the ground residue smoked considerably, the orange colour on the surface was doubtless due to this vapour.

The smell was very peculiar, SH_2 was quite perceptible, but was not the dominant odour.

The maximum temperature occurred at about 20 minutes after exposure, and a thermometer placed in the centre showed a temperature of over 600° F. (310°·6 C.). The temperature might have been somewhat higher, as the thermometer had to be withdrawn for fear of fracture.

The paper was burned through on which the deposit was placed. After half an hour the deposit began to cool rapidly.

It is to be noticed that the heat appears to play an important part in the changes which take place, as it was observed that the residue at the base of the cone remained unchanged in appearance although more exposed to the action of the air than other portions.

It may also be noted that after the residue has gone through this heating process the physical characteristics are considerably changed.

When taken out of the exploding vessel the residue is always difficult to pound in the mortar, being somewhat unctuous or greasy to the touch, but after the development of the heating phase it becomes crisp and powdery.

Determinations of heat absorbed by calorimeter. *Temperature of room* 62°.

Experiment 129.

Temperature of calorimeter	58°·95 F.
„ 30,000 grs. water	79·0 „
Water poured into calorimeter.	
After 1 minute, temperature	78·24 „
„ 2 „ „	78·22 „
„ 4 „ „	78·10 „
„ 6 „ „	78·00 „

Hence loss of heat 0°·76 F. in one minute.

Experiment 130.

Temperature of calorimeter	60°·2 F.
„ water	77·6 „
After 1 minute, temperature	76·8 „
„ 2 „ „	76·7 „
„ 3 „ „	76·62 „
„ 4 „ „	76·6 „
„ 6 „ „	76·5 „

Hence loss of heat 0°·8 F. in one minute.

Experiment 131.

Temperature of calorimeter	61°·08 F.
„ water	71·4 „
After 1 minute, temperature	71·0 „
„ 3 „ „	71·0 „
„ 5 „ „	70·95 „

Loss of heat 0°·4 F. in one minute.

Experiment 132.

Temperature of calorimeter	62°·1 F.
„ water	70·8 „
After 1 minute, temperature	70·4 „
„ 2 „ „	70·4 „

Loss of heat 0°·4 F. in one minute.

Experiment 133.

Temperature of calorimeter	62°·6 F.
„ 30,000 grs. water	70·6 „
Water poured into calorimeter.	
After 1 minute, temperature	70·25 „
„ 2 „ „	70·2 „

Loss of heat 0°·35 F. in one minute.

Experiment 134.

Temperature of calorimeter	63°·45 F.
„ water	70·2 „
After 1 minute, temperature	70·0 „
„ 2 „ „	70·0 „

Loss of heat 0°·2 F. in one minute.

Experiment 135.

Temperature of calorimeter	64°·05 F.
„ water	70·0 „
After 1 minute, temperature	69·82 „
„ 2 „ „	69·8 „

Hence loss of heat 0°·18 F. in one minute.

From the above and similar experiments the following table of loss of heat (the difference of temperature between water and original state of calorimeter being taken as argument) was arranged.

	Difference of temperature.	Loss of heat.	Loss of heat.	
For 30,000 grs. water	2° F.	0°·08 F.	0°·13 F.	For large explosion-vessel. Calorimeter with 25,000 grs. of water.
	4 „	0·16 „	0·26 „	
	6 „	0·24 „	0·39 „	
	8 „	0·32 „	0·52 „	
	10 „	0·40 „	0·65 „	
	12 „	0·48 „	0·78 „	
	14 „	0·56 „	0·91 „	
	16 „	0·64 „	1·04 „	
	18 „	0·72 „	1·18 „	
	20 „	0·80 „	1·31 „	
	22 „	0·88 „	1·44 „	
	24 „	0·96 „	1·57 „	
	26 „	1·04 „	1·70 „	
	27 „	..	1·77 „	
	28 „	..	1·83 „	
	29 „	..	1·90 „	

Experiments for the determination of the specific heats of the vessels used for determining the heat generated by explosion.

In all cases the vessel was boiled, and then kept for five minutes suspended in the escaping steam; it was then transferred to the calorimeter containing 30,000 grs. of distilled water.

Experiment 141.—Weight of vessel, 21,311·6 grs. (1381·0 grms.).

Temperature of air		58°·8 F.
,, steam		211·65 ,,
,, calorimeter before immersion of vessel		58·88 ,,
,, calorimeter after thermometer became stationary		70·08 ,,
Loss of heat in vessel	211°·65−70°·08+0°·2	=141·77 ,,
Gain of heat in water	11°·2 +0°·44=	11·64 ,,

Hence specific heat of vessel=·1156.

Experiment 142.—The same vessel.

Temperature of air		59°·0 F.
,, steam		211·65 ,,
,, calorimeter before experiment		62·21 ,,
,, ,, after ,,		73·20 ,,
Loss of heat in vessel	211°·65−73°·20+0°·2	=138·65 ,,
Gain of heat in water	10°·99+0°·44=	11·43 ,,

Hence specific heat of vessel=·1158.

Experiment 143.—The same vessel.

Temperature of air		60°·20 F.
,, steam		212·20 ,,
,, calorimeter before experiment		61·11 ,,
,, ,, after ,,		72·20 ,,
Loss of heat in vessel	212°·20−72°·20+0°·20=	140·20 ,,
Gain of heat in water	11°·09+0°·44=	11·53 ,,

Hence specific heat of vessel=·1155.

Experiment 144.—The same vessel.

Temperature of air		60°·20 F.
,, steam		212·10 ,,
,, calorimeter before experiment		65·10 ,,
,, ,, after ,,		75·95 ,,
Loss of heat in vessel	212°·20−75°·95+0°·2	=136·45 ,,
Gain of heat in water	10°·85+0°·44=	11·29 ,,

Hence specific heat of vessel=·1163.

Hence mean specific heat of vessel from four experiments, ·1158.

Experiment 167.—Weight of vessel, 52,931·6 grs. (3430 grms.).

Temperature of air		60°·0	F.
,, steam		211·14	,,
,, calorimeter before experiment		55·75	,,
,, ,, after ,,		84·52	,,
Loss of heat in vessel	211°·14−84°·52+0°·2 =	126·82	,,
Gain of heat in water (25,000 grs.)	28°·77+1°·86=	30·63	,,

Hence specific heat of vessel=·1140.

Experiment 168.—The same vessel.

Temperature of air		62°·0	F.
,, steam		211·14	,,
,, calorimeter before experiment		55·48	,,
,, ,, after ,,		84·10	,,
Loss of heat in vessel	211°·14−84°·10+0°·2 =	127·24	,,
Gain of heat in water	28°·60+1°·85=	30·40	,,

Hence specific heat of vessel=·1132.

Experiment 169.—The same vessel.

Temperature of air		62°·0	F.
,, steam		211·14	,,
,, calorimeter before experiment		55·55	,,
,, ,, after ,,		84·30	,,
Loss of heat in vessel	211°·14−84°·30+0°·2 =	127·04	,,
Gain of heat in water	28°·75+1°·86=	30·61	,,

Hence specific heat of vessel=·1138.

Hence mean specific heat of vessel from three experiments=·1137.

Determination of heat evolved by the various powders.

A.—SMALL explosion-vessel.

		Grs.
Weight of water, 30,000 grs.	equivalent in water	30,000·0
,, explosion-vessel, 21,311·6 grs.	,, ,,	2,465·8
,, powder products	,, ,,	28·5
Equivalent in water, of contents of calorimeter		32,494·3
When 200 grs. of powder used, the equivalent in water of the contents of the calorimeter is		32,503·8

Experiment 146.—Exploded 150 grs. CURTIS and HARVEY'S No. 6.

Temperature of calorimeter before explosion . 61°·50 F.
„ „ after „ . 67·78 „
Hence difference . . . . . 6°·28+0°·24= 6·52 „
Hence heat evolved=784·0 gramme-units centigrade.

Experiment 147.—Exploded 150 grs. Spanish.

Temperature of calorimeter before explosion . 65°·10 F.
„ „ after „ . 71·20 „
Hence difference . . . . . 6°·10+0°·24= 6·34 „
Hence heat evolved=762·5 gramme-units centigrade.

Experiment 148.—Exploded 150 grs. R. L. G.

Temperature of calorimeter before explosion . 56°·28 F.
„ „ after „ . 62·07 „
Hence difference . . . . . 5°·79+0°·24= 6·03 „
Hence heat evolved=725·1 gramme-units centigrade.

Experiment 149.—Exploded 150 grs. pebble.

Temperature of calorimeter before explosion . 60°·42 F.
„ „ after „ . 66·10 „
Hence difference . . . . . 5°·68+0°·24= 5·92 „
Hence heat evolved=711·9 gramme-units centigrade.

Experiment 150.—Exploded 150 grs. F. G.

Temperature of calorimeter before explosion . 65°·16 F.
„ „ after „ . 70·80 „
Hence difference . . . . . 5°·64+0°·23= 5·87 „
Hence heat evolved=706·45 gramme-units centigrade.

Experiment 153.—With 200 grs. pebble.

Failure; the plug being spoiled by the explosion.

Experiment 154.—Exploded 150 grs. F. G.

Temperature of calorimeter before explosion . 49°·55 F.
„ „ after „ . 55·45 „
Hence difference . . . . . 59°·0+0°·24= 6·14 „
Hence heat evolved=738·9 gramme-units centigrade.

Experiment 155.—Exploded 150 grs. R. L. G.

Temperature of calorimeter before explosion . 86°·00 F.
„ „ after „ . 91·73 „
Hence difference . . . . . 5°·73+0°·24= 5·97 „
Hence heat evolved=718·4 gramme-units centigrade.

Experiment 156.—Exploded 150 grs. pebble.

Temperature of calorimeter before explosion . 56°·07 F.
„ „ after „ . 61·95 „
Hence difference . . . . . 5°·87+0°·23= 6·10 „
Hence heat evolved=734·1 gramme-units centigrade.

Experiment 157.—Exploded 150 grs. Spanish.

Temperature of calorimeter before explosion . 56°·90 F.
„ „ after „ . 63·06 „
Hence difference . . . . . 6°·16+0°·25= 6·41 „
Hence heat evolved=771·4 gramme-units centigrade.

Experiment 158.—Exploded 150 Curtis and Harvey's No. 6.

Temperature of calorimeter before explosion . 57°·92 F.
„ „ after „ . 63·87 „
Hence difference . . . . . 5°·95+0°·24= 6·19 „
Hence heat evolved=744·9 gramme-units centigrade.

Experiment 159.—Exploded 150 grs. mining.

Temperature of calorimeter before explosion . 58°·50 F.
„ „ after „ . 62·54 „
Hence difference . . . . . 4°·04+0°·16= 4·02 „
Hence heat evolved=505·5 gramme-units centigrade.

Experiment 160.—Exploded 150 grs. R. L. G.

Temperature of calorimeter before explosion . 62°·42 F.
„ „ after „ . 68·06 „
Hence difference . . . . . 5°·64+0°·24= 5·88 „
Hence heat evolved=707·5 gramme-units centigrade.

Experiment 161.—Exploded 150 grs. pebble.

Temperature of calorimeter before explosion . 49°·05 F.
„ „ after „ . 54·59 „
Hence difference . . . . . 5°·54+0°·23= 5·77 „
Hence heat evolved=694·4 gramme-units centigrade.

Experiment 162.—Exploded 150 grs. mining.

Temperature of calorimeter before explosion . 56°·80 F.
,, ,, after ,, . 60·82 ,,
Hence difference . . . . . . 4°·02+0°·20= 4·22 ,,

Hence heat evolved=507·9 gramme-units centigrade.

Experiment 163.—Exploded 150 grs. CURTIS and HARVEY'S No. 6.

Temperature of calorimeter before explosion . 52°·80 F.
,, ,, after ,, . 58·65 ,,
Hence difference . . . . . . 5°·85+0°·24= 6·09 ,,

Hence heat evolved=732·9 gramme-units centigrade.

Experiment 164.—Exploded 150 grs. F. G.

Temperature of calorimeter before explosion . 57°·42 F.
,, ,, after ,, . 63·26 ,,
Hence difference . . . . . . 5°·84+0°·24= 6·08 ,,

Hence heat evolved=731·7 gramme-units centigrade.

Experiment 165.—Exploded 150 grs. Spanish.

Temperature of calorimeter before explosion . 55°·70 F.
,, ,, after ,, . 61·72 ,,
Hence difference . . . . . . 6°·02+0°·24= 6·26 ,,

Hence heat evolved=753·4 gramme-units centigrade.

Experiment 166.—Exploded 150 grs. pebble.

Temperature of calorimeter before explosion . 61°·12 F.
,, ,, after ,, . 66·80 ,,
Hence difference . . . . . . 5°·68+0°·22= 5·90 ,,

Hence heat evolved=710·0 gramme-units centigrade.

Experiment 151.—Exploded 200 grs. mining.

Temperature of calorimeter before explosion . 60°·38 F.
,, ,, after ,, . 65·87 ,,
Hence difference . . . . . . 5°·49+0°·22= 5·71 ,,

Hence heat evolved=512·7 gramme-units centigrade.

Experiment 152.—Exploded 200 grs. CURTIS and HARVEY'S No. 6.

Temperature of calorimeter before explosion . 64°·95 F.
,, ,, after ,, . 73·00 ,,
Hence difference . . . . . . 8°·05+0°·32= 8·37 ,,

Hence heat evolved=755·7 gramme-units centigrade.

B.—LARGE explosion-vessel.

		Grs.
Weight of water, 25,000 grs.	equivalent in water	25,000·0
„ explosion-vessel, 52,931·6 grs.	„ „	6,018·3
„ powder products, 400 grs.	„ „	76·0
Equivalent in water, of contents of calorimeter		31,094·3

Experiment 171.—Exploded 400 grs. pebble.

Temperature of calorimeter before explosion . 54°·38 F.
„ „ after „ . 69·43 „
Hence difference . . . . . . 15°·05+1°·24=16·29 „

Hence heat evolved=703·41 gramme-units centigrade.

Experiment 172.—Exploded 400 grs. R. L. G.

Temperature of calorimeter before explosion . 57°·08 F.
„ „ after „ . 72·44 „
Hence difference . . . . . . 15°·36+1°·26=16·62 „

Hence heat evolved=717·7 gramme-units centigrade.

Experiment 173.—Exploded 400 grs. R. L. G.

Temperature of calorimeter before explosion . 57°·22 F.
„ „ after „ . 72·74 „
Hence difference . . . . . . 15°·52+1°·26=16·78 „

Hence heat evolved=724·7 gramme-units centigrade.

Experiment 174.—Exploded 400 grs. pebble.

Temperature of calorimeter before explosion . 57°·13 F.
„ „ after „ . 72·42 „
Hence difference . . . . . . 15°·29+1°·26=16·55 „

Hence heat evolved=714·7 gramme-units centigrade.

Experiment 175.—Exploded 400 grs. pebble.

Temperature of calorimeter before explosion . 56°·40 F.
„ „ after „ . 72·00 „
Hence difference . . . . . . 15°·6+1°·27=16·87 „

Hence heat evolved=728·5 gramme-units centigrade.

Experiment 176.—Exploded 400 grs. R. L. G.

Temperature of calorimeter before explosion . 67°·12 F.
" " after " . 82·38 "
Hence difference . . . . . . 15°·26+1°·26=16·52 "

Hence heat evolved=713·4 gramme-units centigrade.

Experiment 177.—Exploded 400 grs. mining.

Temperature of calorimeter before explosion . 53°·27 F.
" " after " . 64·13 "
Hence difference . . . . . 10°·86+0°·71=11·57 "

Hence heat evolved=499·65 gramme-units centigrade.

Experiment 178.—Exploded 400 grs. mining.

Temperature of calorimeter before explosion . 57°·25 F.
" " after " . 68·27 "
Hence difference . . . . . 11°·02+0°·72=11·74 "

Hence heat evolved=507·0 gramme-units centigrade.

Experiment 179.—Exploded 400 grs. mining.

Temperature of calorimeter before explosion . 64°·73 F.
" " after " . 76·03 "
Hence difference . . . . . 11°·30+0°·74=12·04 "

Hence heat evolved=520·0 gramme-units centigrade.

Experiment 181.—Exploded 400 grs. Spanish.

Temperature of calorimeter before explosion . 51°·62 F.
" " after " . 67·76 "
Hence difference . . . . . 16°·14+1°·32=17·46 "

Hence heat evolved=754·0 gramme-units centigrade.

Experiment 182.—Exploded 400 grs. Spanish.

Temperature of calorimeter before explosion . 66°·90 F.
" " after " . 83·21 "
Hence difference . . . . . 16°·31+1°·33=17·64 "

Hence heat evolved=761·8 gramme-units centigrade.

Experiment 183.—Exploded 400 grs. special mining.

Temperature of calorimeter before explosion . 52°·72 F.
" " after " . 63·58 "
Hence difference . . . . . 10°·86+0°·71=11·57 "

Hence heat evolved=499·65 gramme-units centigrade.

Experiment 184.—Exploded 400 grs. Spanish.
Temperature of calorimeter before explosion . 58°·52 F.
„ „ after „ . 75·03 „
Hence difference . . . . . . 16°·51+1°·35=17·86 „
Hence heat evolved=771·3 gramme-units centigrade.

Experiment 185.—Exploded 400 grs. CURTIS and HARVEY'S No. 6.
Temperature of calorimeter before explosion . 53°·19 F.
„ „ after „ . 69·26 „
Hence difference . . . . . . 16°·07+1°·31=17·38 „
Hence heat evolved=750·6 gramme-units centigrade.

Experiment 186.—Exploded 400 grs. CURTIS and HARVEY'S No. 6.
Temperature of calorimeter before explosion . 55°·80 F.
„ „ after „ . 72·19 „
Hence difference . . . . . . 16°·39+1°·33=17·72 „
Hence heat evolved=765·3 gramme-units centigrade.

Experiment 187.—Exploded 400 grs. CURTIS and HARVEY'S No. 6.
Temperature of calorimeter before explosion . 53°·48 F.
„ „ after „ . 69·58 „
Hence difference . . . . . . 16°·10+1°·32=17·42 „
Hence heat evolved=752·3 gramme-units centigrade.

Experiment 189.—Exploded 400 grs. F. G.
Temperature of calorimeter before explosion . 55°·61 F.
„ „ after „ . 71·26 „
Hence difference . . . . . . 15°·65+1°·28=16·93 „
Hence heat evolved=731·1 gramme-units centigrade.

Experiment 191.—Exploded 400 grs. F. G.
Temperature of calorimeter before explosion . 53°·04 F.
„ „ after „ . 68·49 „
Hence difference . . . . . . 15°·45+1°·27=16·72 „
Hence heat evolved=722·1 gramme-units centigrade.

Experiment 192.—Exploded 400 grs. F. G.
Temperature of calorimeter before explosion . 53°·95 F.
„ „ after „ . 69·59 „
Hence difference . . . . . . 15°·64+1°·28=16·92 „
Hence heat evolved=730·7 gramme-units centigrade.

Experiment 193.—Fired 5960 grs. = 386·2 grms. mining powder in cylinder No. 6, containing 14,900 grs.

Temperature of gas = 55°·5 F. = 13°·1 C. Bar. 30·025 = 762·35 millims.
Amount of gas = 27″·94 − 8″·35 = 19″·59.
= 444·8 × 19·59 + 18 cub. inches.
= 8731·63 cub. inches.
= 143,076·49 cub. centims. at 13°·1 C., and 762·35 millims.
= 143,518·9 cub. centims. at 13°·1 C., and 760 millims.
= 136,944·2 cub. centims. at 0° C., and 760 millims.
= 354·6 times original volume.

Experiment 194.—Fired 4650 grs. (301·3 grms.) mining powder in cylinder containing 15,500 grs.

In letting the gas escape, found for the first time that the gas lighted, giving rise to an intensely suffocating smell of sulphurous acid, showing, as was indeed otherwise apparent, that sulphydric acid was present in large quantities. Sealed up gases for examination.

Did not take out the deposit as usual, but after the gases had escaped, filled the cylinder, by displacement, with distilled water, entirely freed from air by long boiling.

On the water touching the deposit it decrepitated with considerable sharpness. When the cylinder was full it was entirely sealed, and reopened after an interval of about 48 hours. The solution was then decanted into bottles, freed from oxygen, and sealed for examination.

δ.	A.	a.	Crush.	Pressure.
·30	·0833	·0417	·015	5·04 tons per square inch.

Experiment 195.—Fired 5960 grs. = 386·2 grms. Curtis and Harvey's No. 6, in cylinder No. 6.

Temperature of gas = 60°·8 F. = 16°·0 C. Bar. 30″·430 = 772·9.
Amount of gas = 444·8 × 13·10 + 18 cub. inches.
= 5,844·88 cub. inches.
= 95,774·2 cub. centims. at 772·9, and 16°·0 C.
= 97,399·8 cub. centims. at 16°·0 C. and 760 millims.
= 92,004·6 cub. centims. at 0° C. and 760 millims.
= 238·23 vols.

Experiment 196.—Fired 4650 grs. = 301·3 grms. Curtis and Harvey's No. 6, in cylinder containing 15,500 grs. Took all the precautions described in experiment 194; observed gas issuing from vessel would not light.

δ.	A.	a.	Crusher.	Pressures.
·30	·0833	·0417	·015	5·04 tons per square inch.

Experiment 197.—Fired 10,000 grs. of mining powder in cylinder containing 15,500 grs. of water. A good deal of gas escaped past crusher-plug.

δ.	A.	a.		Crush.		Pressure.
·700	·0833	·0417	A	·220	=	20·8 tons per square inch.
			B	·221	=	20·8 ,,
			C	·226	=	21·2 ,,

Deposit approximately=2025 grs. water.

Experiment 198.—Fired 10,000 grs. Curtis and Harvey's No. 6.

The greater proportion of the gases escaped, the gas getting between the steel barrel and the coil, by the screw of the crusher-plug, causing the coil to crush and indenting the steel and the coil in a very remarkable manner.

δ.	A.	a.		Crush.		Pressure.
·70	·0833	·0417	A	·214	=	19·95 tons per square inch.
			B	·197	=	19·11 ,,
			C	·197	=	19·11 ,,

Experiment 199.—A series of experiments in guns of various calibres with mining powder.

Experiment 200.—Fired cylinder hooped with B. R. iron No. 3, and with a capacity of 11,000 grs. water, with a charge of 8750 grs. pebble, and 2250 grs. F. G., 11,000 grs. in all. Copper in crusher-plug crushed beforehand to 35 tons.

Head of crusher-plug broke off by the explosion, and gas escaped, taking, as nearly as could be guessed, from one to two seconds to escape.

Outside diameter of cylinder before firing . . 10″·368
,, ,, after ,, . . 10″·393

Pressure developed over 39 tons, but not reliable, owing to the escape of the gases.

Experiment 201.—Fired cylinder hooped with Siemens' mild steel No. 2, and with a capacity of 11,200 grs. water, with a charge of 11,200 grs. powder, consisting of 8750 grs. pebble and 2450 grs. F. G.

Gas escaped with great rapidity past the firing cone, which was of course destroyed; great difficulty found in extracting the crusher-piston, which had been jammed by the compression of the chamber in which it was placed. Its record was therefore valueless.

Experiment 202.—Fired same cylinder with a charge of 13,640 grs. powder, of which 8375 grs. were pebble, the rest F. G. Crusher-plug blew out before charge fully fired.

Experiment 225.—Fired 9000 grs. pebble and 3000 grs. F. G. in cylinder No. 2, containing 12,680 grs. water, less 670 grs. occupied by internal crusher-gauge. One internal crusher used; gas escaped slowly.

δ.	A.	a.		Crush.		Pressure.
1·0	·0417	·0833	B crusher	·193	=	42·52 tons per square inch.
			C ,,	·193	=	42·72 ,,

Experiment 230.—Fired in No. 2 cylinder (Siemens'), containing 12,680 grs. 11,360 grs. mining powder, same as that tested in the 2·5-inch B. L. gun on 4th September, 1878. The gas escaped through the insulated cone, almost at once. It did not escape with any violence.

Pressures indicated were as follow:—

δ.	A.	a.		Crush.		Pressure.	
1	·0417	·0833	A	·165	=	36·8 tons per square inch.	A, doubtful; piston being jammed.
			B	·200	=	43·9 ,,	
			C	·200	=	43·9 ,,	

Experiment 233.—Fired 9000 grs. pebble, and 4000 grs. F. G., total 13,000 grs. (842·4 grms.), in No. 2 Siemens' cylinder, cubic contents 12,680 grs.—2000 grs. for two internal crusher-gauges; total contents, 10,680 grs. The pressure forced out the closing-plugs by shearing the threads.

δ.	A.	a.		Crush.		Pressure.
1·21	·0417	·0833	A crusher	·256	=	55·6 tons per square inch.
			B ,,	·256	=	55·6 ,,
			C ,,	·260	=	56·8 ,,

NOTE.

(Added 9th March, 1880.)

Since this memoir was submitted to the Society, we have been led, in consequence of a communication made to us by Dr. DEBUS, to modify considerably our views with regard to the formation of hyposulphite.

The experiments rendered necessary by Dr. DEBUS' discovery are fully described and discussed in a note submitted to the Royal Society,* but as the facts there given have led us to the conclusion "that although it would seem that in certain cases and under certain exceptional circumstances potassium hyposulphite does exist as a secondary, it exists in no case as a primary product, and should not, therefore, be reckoned among the normal constituents of powder residues," we have recalculated the whole of our analytical results, and we append two tables, Nos. XII. and XIII., giving for each experiment the products of decomposition calculated on the hypothesis that prior to removal from the explosion vessel the whole of the hyposulphite found was in the form of mono or polysulphides.

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* Proc. Roy. Soc., vol. xxx., p. 198.

TABLE XII.—Showing the mean analytical results obtained from an examination of the solid and gaseous products of decomposition of Pebble, R. L. G., and F. G. powders; showing also the same particulars with respect to four other powders.

No. of experiments.	Nature of powder.	Mean density of products of combustion.	Percentage composition by volume of the gas.							Percentage composition by weight of the solid residue.								
			Carbonic anhydride.	Carbonic oxide.	Nitrogen.	Sulphydric acid.	Marsh gas.	Hydrogen.	Oxygen.	Potassium carbonate.	Potassium sulphate.	Potassium monosulphide.	Potassium sulphocyanate.	Potassium nitrate.	Potassium oxide.	Ammonium sesquicarbonate.	Sulphur.	Charcoal.
8	Pebble, W. A. . . .	·10	46·66	14·76	32·75	3·13	..	2·70	..	58·56	15·84	20·50	0·09	0·51	..	0·17	4·33	..
7		·20	44·78	16·09	31·31	4·23	..	3·59	..	58·01	13·85	20·41	0·06	..	..	0·09	7·58	..
9		30	47·03	15·51	31·71	2·90	..	2·84	..	60·09	12·74	19·24	0·21	0·03	..	0·17	7·52	..
12		·40	49·52	13·95	32·16	1·70	0·32	2·35	..	57·25	13·69	18·52	0·25	0·08	..	0·07	8·74	1·40
14		·50	49·82	13·36	32·19	1·96	0·58	2·08	..	57·04	12·12	23·02	0·23	0·20	..	0·08	7·31	..
37		·60	49·48	13·75	31·83	2·24	0·55	2·15	..	59·00	13·82	17·68	0·36	0·32	..	0·06	8·76	..
38		·70	49·93	12·51	32·08	3·18	0·35	1·95	..	54·64	13·91	22·72	0·41	0·26	..	0·06	8·00	..
43		·80	51·54	11·88	32·61	1·96	0·34	1·67	..	62·35	10·94	16·84	0·06	0·33	..	0·08	9·40	..
77		·90	51·75	10·87	32·72	2·13	0·68	1·85	..	66·43	9·45	11·92	0·59	0·44	..	0·12	11·05	..
		Means	48·95	13·63	32·15	2·60	0·31	2·35	..	59·26	12·93	18·98	0·25	0·24	..	0·10	8·08	0·16
		Highest	51·75	16·09	32·75	4·23	0·68	3·59	..	66·43	15·84	23·02	0·59	0·51	..	0·17	11·05	1·40
		Lowest	44·78	10·87	31·31	1·70	..	1·67	..	54·64	9·45	11·92	0·06	0·03	..	0·06	4·33	..
1	R. L. G., W. A. . . .	·10	49·00	8·98	35·60	4·06	0·29	2·07	..	55·41	21·58	16·68	..	0·59	..	0·06	4·93	0·75
3		·20	46·56	11·47	35·13	3·58	0·07	2·62	0·57	55·47	24·44	13·08	0·05	0·12	..	0·06	6·76	0·02
4		·30	49·35	11·60	32·96	3·11	..	2·98	..	54·16	25·03	13·76	0·05	0·03	..	0·04	6·93	..
11		·40	50·25	10·84	34·23	1·93	0·28	2·47	..	51·82	24·35	17·00	0·17	0·13	..	0·04	6·49	..
70		·50	47·21	17·04	30·29	1·61	0·84	3·01	..	64·77	4·96	19·47	0·30	0·53	..	0·11	9·86	..
39		·60	46·29	14·52	32·40	4·29	0·36	2·14	..	66·43	10·90	11·85	0·28	0·46	..	0·09	9·99	..
96		·60	50·22	13·93	31·74	1·62	0·35	2·14	..	64·88	11·16	13·91	0·26	..	..	0·11	9·68	..
41		·70	49·75	13·38	31·94	2·85	0·55	1·53	..	63·25	11·04	15·34	0·51	0·44	..	0·08	9·34	..
44		·80	51·62	12·16	32·16	1·56	0·77	1·72	..	67·00	8·88	10·92	0·25	0·18	..	0·11	12·66	..
68		·90	52·65	10·73	32·65	1·90	0·80	1·27	..	67·16	8·71	12·50	0·38	0·20	..	0·15	10·90	..
		Means	49·29	12·47	32·91	2·65	0·43	2·19	0·06	61·03	15·10	14·45	0·22	0·27	..	0·08	8·74	0·08
		Highest	52·65	17·04	35·60	4·29	0·84	3·01	0·57	67·16	25·03	19·47	0·51	0·59	..	0·15	12·66	0·75
		Lowest	46·29	8·98	30·29	1·56	0·07	1·27	..	51·82	4·96	10·92	0·05	0·03	..	0·04	4·93	..
16	F. G., W. A.	·10	44·76	16·25	32·57	2·26	0·18	3·83	0·15	52·43	19·00	18·30	..	0·21	5·74	0·07	4·25	..
17		·20	47·41	12·35	32·35	3·76	..	4·13	..	60·20	24·55	8·30	0·02	0·08	..	0·15	6·70	..
18		·30	50·45	11·33	32·22	2·21	..	3·51	0·28	47·17	23·24	19·23	0·07	0·10	..	0·01	10·18	..
19		·40	51·79	10·31	32·54	2·00	..	3·36	..	48·37	23·46	21·50	0·08	0·10	..	0·04	6·45	..
75		·50	51·04	10·38	33·15	2·20	0·27	2·96	..	57·97	21·45	12·55	0·07	0·09	..	0·08	7·79	..
40		·60	52·00	9·60	33·28	2·26	0·18	2·68	..	45·55	24·15	20·12	0·17	0·18	3·49	0·01	6·33	..
42		·70	53·02	7·91	34·26	2·03	0·50	2·13	0·15	48·39	23·61	20·90	0·26	0·21	..	0·03	6·60	..
47		·80	51·80	8·32	34·64	2·61	0·41	2·04	0·18	47·80	23·15	21·98	0·26	0·28	..	0·04	6·49	..
69		·90	53·34	7·71	33·81	2·95	0·16	2·04	..	54·17	19·64	18·88	0·27	0·28	..	0·03	6·73	..
		Means	50·63	10·47	33·21	2·48	0·19	2·96	0·08	51·34	22·47	17·97	0·13	0·17	1·02	0·05	6·83	..
		Highest	53·34	16·25	34·64	3·76	0·50	4·13	0·28	60·20	24·55	21·98	0·27	0·28	5·74	0·15	10·18	..
		Lowest	44·76	7·71	32·22	2·00	..	2·04	..	45·55	19·00	8·30	..	0·08	..	0·01	4·25	..
78	R. F. G., W. A. . . .	·70	52·40	8·86	34·51	1·60	0·12	2·51	..	60·17	22·35	9·14	0·04	0·06	..	0·05	8·19	..
79	Spanish spherical . .	·70	53·34	4·62	37·80	2·74	..	1·29	0·21	35·66	48·55	7·72	0·04	0·95	..	0·04	7·04	..
196	CURTIS & HARVEY, No. 6	·30	50·22	7·52	34·46	2·08	2·46	3·26	..	59·10	21·65	12·42	..	0·29	..	0·09	6·45	..
194	Mining powder . . .	·30	32·15	33·75	19·03	7·10	2·73	5·24	..	41·36	0·59	37·10	2·95	0·09	..	1·78	14·11	2·02

TABLE XIII.—Composition by weight of the products of combustion of 1 gramme of fired gunpowder of the under-mentioned natures, and of various gravimetric densities.

No. of experiments.	Nature of powder.	Mean density of products of combustion.	Proportions by weight of gaseous products.							Proportions by weight of the solid residue.									Proportion by weight of total gaseous products.	Proportion by weight of total solid products.	Water.
			Carbonic anhydride.	Carbonic oxide.	Nitrogen.	Sulphydric acid.	Marsh gas.	Hydrogen.	Oxygen.	Potassium carbonate.	Potassium sulphate.	Potassium mono-sulphide.	Potassium sulpho-cyanate.	Potassium nitrate.	Potassium oxide.	Ammonium sesqui-carbonate.	Sulphur.	Charcoal.			
8	Pebble, W. A.	·10	·2634	·0530	·1176	·0137	..	·0007	..	·3174	·0858	·1111	·0005	·0027	..	·0009	·0234	..	·4484	·5418	·0095
7		·20	·2505	·0572	·1114	·0183	..	·0009	..	·3203	·0765	·1127	·0003	..	..	·0005	·0419	..	·4383	·5522	·0095
9		·30	·2609	·0548	·1120	·0124	..	·0007	..	·3303	·0700	·1058	·0012	·0002	..	·0009	·0413	..	·4408	·5497	·0095
12		·40	·2683	·0481	·1109	·0071	·0007	·0006	..	·3176	·0760	·1028	·0014	·0004	..	·0004	·0485	·0077	·4357	·5548	·0095
14		·50	·2768	·0472	·1137	·0084	·0012	·0005	..	·3096	·0658	·1249	·0012	·0011	..	·0004	·0397	..	·4478	·5427	·0095
37		·60	·2695	·0477	·1103	·0094	·0011	·0005	..	·3257	·0763	·0976	·0020	·0018	..	·0003	·0484	..	·4385	·5520	·0095
38		·70	·2748	·0438	·1124	·0135	·0007	·0005	..	·2977	·0758	·1238	·0022	·0014	..	·0003	·0436	..	·4457	·5448	·0095
43		·80	·2785	·0409	·1121	·0082	·0007	·0004	..	·3428	·0601	·0926	·0003	·0018	..	·0004	·0517	..	·4408	·5497	·0095
77		·90	·2743	·0367	·1103	·0087	·0014	·0005	..	·3711	·0528	·0666	·0033	·0025	..	·0007	·0617	..	·4318	·5587	·0095
		Means	·2685	·0477	·1123	·0111	·0006	·0006	..	·3258	·0710	·1042	·0014	·0013	..	·0005	·0445	·0008	·4409	·5496	·0095
		Highest	·2785	·0572	·1176	·0183	·0014	·0009	..	·3711	·0858	·1249	·0033	·0027	..	·0009	·0617	..	·4484	·5587	·0095
		Lowest	·2505	·0367	·1103	·0071	..	·0004	..	·2977	·0528	·0666	·0003	..	..	·0003	·0234	..	·4318	·5418	·0095
1	R. L. G., W. A.	·10	·2653	·0309	·1226	·0170	·0006	·0005	..	·3059	·1191	·0921	..	·0033	..	·0003	·0272	·0041	·4369	·5520	·0111
3		·20	·2497	·0391	·1198	·0148	·0001	·0006	·0022	·3121	·1375	·0736	·0003	·0007	..	·0003	·0380	·0001	·4263	·5626	·0111
4		·30	·2633	·0394	·1119	·0128	..	·0007	..	·3037	·1403	·0772	·0003	·0002	..	·0002	·0389	..	·4281	·5608	·0111
11		·40	·2702	·0371	·1172	·0080	·0006	·0006	..	·2877	·1352	·0944	·0010	·0007	..	·0002	·0360	..	·4337	·5552	·0111
70		·50	·2601	·0581	·1053	·0068	·0017	·0007	..	·3601	·0276	·1083	·0017	·0030	..	·0006	·0548	..	·4327	·5561	·0112
39		·60	·2480	·0495	·1101	·0177	·0007	·0005	..	·3739	·0614	·0667	·0016	·0026	..	·0005	·0562	..	·4265	·5629	·0111
96		·60	·2672	·0471	·1074	·0067	·0007	·0005	..	·3629	·0624	·0778	·0015	..	..	·0006	·0541	..	·4296	·5593	·0111
41		·70	·2655	·0454	·1085	·0118	·0011	·0004	..	·3519	·0614	·0853	·0028	·0024	..	·0004	·0520	..	·4327	·5562	·0111
44		·80	·2651	·0397	·1051	·0062	·0014	·0040	..	·3802	·0504	·0620	·0014	·0010	..	·0006	·0718	..	·4215	·5674	·0111
68		·90	·2760	·0358	·1089	·0077	·0015	·0003	..	·3764	·0488	·0700	·0021	·0011	..	·0008	·0611	..	·4302	·5603	·0111
		Means	·2630	·0422	·1117	·0109	·0008	·0009	·0002	·3415	·0844	·0807	·0013	·0015	..	·0004	·0490	·0004	·4298·	·5591	·0111
		Highest	·2760	·0581	·1226	·0177	·0017	·0040	·0022	·3802	·1403	·1083	·0021	·0033	..	·0008	·0718	·0041	·4369	·5674	·0112
		Lowest	·2480	·0309	·1051	·0062	·0001	·0003	..	·2877	·0276	·0620	..	..	..	·0002	·0272	..	·4215	·5520	·0111
16	F. G., W. A.	·10	·2512	·0580	·1163	·0098	·0004	·0010	·0006	·2872	·1042	·1003	..	·0011	·0315	·0004	·0233	..	·4372	·5480	·0148
17		·20	·2490	·0413	·1081	·0153	..	·0010	..	·3434	·1401	·0473	·0001	·0005	..	·0009	·0382	..	·4147	·5705	·0148
18		·30	·2621	·0374	·1065	·0089	..	·0008	·0010	·2683	·1321	·1093	·0003	·0005	..	·0001	·0579	..	·4167	·5685	·0148
19		·40	·2765	·0350	·1105	·0082	..	·0008	..	·2680	·1300	·1192	·0004	·0006	..	·0002	·0358	..	·4310	·5542	·0148
75		·50	·2665	·0344	·1102	·0089	·0005	·0007	..	·3269	·1210	·0708	·0004	·0005	..	·0005	·0439	..	·4212	·5640	·0148
40		·60	·2782	·0327	·1133	·0093	·0003	·0007	..	·2508	·1330	·1108	·0009	·0010	·0192	·0001	·0349	..	·4345	·5507	·0148
42		·70	·2804	·0266	·1152	·0083	·0010	·0005	·0006	·2674	·1305	·1155	·0014	·0012	..	·0002	·0364	..	·4326	·5526	·0148
47		·80	·2752	·0281	·1171	·0107	·0008	·0005	·0007	·2640	·1278	·1214	·0014	·0015	..	·0002	·0358	..	·4331	·5521	·0148
69		·90	·2812	·0259	·1134	·0120	·0003	·0005	..	·2989	·1084	·1042	·0015	·0016	..	·0002	·0371	..	·4333	·5519	·0148
		Means	·2689	·0355	·1123	·0101	·0004	·0007	·0003	·2861	·1252	·0999	·0007	·0009	·0056	·0003	·0381	..	·4282	·5569	·0148
		Highest	·2892	·0580	·1171	·0153	·0010	·0010	·0010	·3434	·1401	·1214	·0015	·0016	·0315	·0009	·0579	..	·4372	·5705	·0148
		Lowest	·2490	·0259	·1065	·0082	..	·0005	..	·2508	·1042	·0473	..	·0005	..	·0001	·0233	..	·4147	·5480	·0148
78	R. F. G., W. A.	·70	·2686	·0289	·1126	·0064	·0002	·0006	..	·3458	·1285	·0525	·0002	·0003	..	·0003	·0471	..	·4173	·5747	·0080
79	Spanish spherical	·70	·2457	·0136	·1108	·0097	..	·0003	·0007	·2186	·2975	·0473	·0002	·0058	..	·0002	·0431	..	·3808	·6127	·0065
196	Curtis & Harvey, No. 6	·30	·2593	·0247	·1132	·0083	·0046	·0008	..	·3413	·1250	·0717	..	·0017	..	·0005	·0372	..	·4109	·5774	·0117
194	Mining powder	·30	·2279	·1522	·0858	·0389	·0070	·0017	..	·1945	·0028	·1745	·0139	·0004	..	·0084	·0664	·0095	·5135	·4704	·0161