

A DICTIONARY
OF
APPLIED CHEMISTRY

BY

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ABBREVIATIONS

OF THE TITLES OF JOURNALS AND BOOKS.

<i>Amer. Chem. J.</i>	American Chemical Journal.
<i>Amer. J. Pharm.</i>	American Journal of Pharmacy.
<i>Amer. J. Sci.</i>	American Journal of Science.
<i>Anal. Fis. Quim.</i>	Anales de la Sociedad Española Física y Quimica.
<i>Analyst</i>	The Analyst.
<i>Annalen</i>	Annalen der Chemie (Justus Liebig).
<i>Ann. Chim. anal.</i>	Annales de Chimie analytique appliquée à l'Industrie, à l'Agriculture. à la Pharmacie et à la Biologie.
<i>Ann. Chim.</i>	Annales de Chimie.
<i>Ann. Falsif.</i>	Annales des Falsifications.
<i>Ann. Inst. Pasteur.</i>	Annales de l'Institut Pasteur.
<i>Ann. Physik.</i>	Annalen der Physik.
<i>Ann. Physique</i>	Annales de Physique.
<i>Annali Chim. Appl.</i>	Annali di Chimica Applicata.
<i>Apoth. Zeit.</i>	Apotheker-Zeitung.
<i>Arch. Pharm.</i>	Archiv der Pharmazie.
<i>Atti R. Accad. Lincei</i>	Atti della Reale Accademia dei Lincei.
<i>Bentl. a. Trim.</i>	Bentley and Trimen. Medicinal Plants.
<i>Ber.</i>	Berichte der Deutschen chemischen Gesellschaft.
<i>Ber. Deut. pharm. Ges.</i>	Berichte der Deutschen pharmazeutischen Gesellschaft.
<i>Bied. Zentr.</i>	Biedermann's Zentralblatt für Agrikulturchemie und rationellen Landwirtschafts-Betrieb.
<i>Bio-Chem. J.</i>	The Bio-Chemical Journal.
<i>Biochem. Zeitsch.</i>	Biochemische Zeitschrift.
<i>Brewers J.</i>	Brewer's Journal.
<i>Bull. Imp. Inst.</i>	Bulletin of the Imperial Institute.
<i>Bull. Soc. chim.</i>	Bulletin de la Société chimique de France.
<i>Chem. Ind.</i>	Chemische Industrie.
<i>Chem. News</i>	Chemical News.
<i>Chem. Soc. Proc.</i>	Journal of the Chemical Society of London. Proceedings.
<i>Chem. Soc. Trans.</i>	Journal of the Chemical Society of London. Transactions.
<i>Chem. Weekblad</i>	Chemisch Weekblad.
<i>Chem. Zeit.</i>	Chemiker Zeitung.
<i>Chem. Zentr.</i>	Chemisches Zentralblatt.
<i>Compt. rend.</i>	Comptes rendus hebdomadaires des Séances de l'Académie des Sciences.
<i>Dingl. poly. J.</i>	Dingler's polytechnisches Journal.
<i>Färber-Zeit.</i>	Färber-Zeitung.
<i>Flück. a. Hanb.</i>	Flückiger and Hanbury. Pharmacographia.
<i>Frdl.</i>	Friedländer's Fortschritte der Teerfarbenfabrikation.
<i>Gazz. chim. ital.</i>	Gazzetta chimica italiana.
<i>Helv. Chim. Acta</i>	Helvetica Chimica Acta.
<i>Jahrb. Min.</i>	Neues Jahrbuch für Mineralogie, Geologie und Palaeontologie.
<i>J. Amer. Chem. Soc.</i>	Journal of the American Chemical Society.
<i>J. Bd. Agric.</i>	Journal of the Board of Agriculture.
<i>J. Franklin Inst.</i>	Journal of the Franklin Institute.
<i>J. Ind. Eng. Chem.</i>	Journal of Industrial and Engineering Chemistry.
<i>J. Inst. Brewing</i>	Journal of the Institute of Brewing.
<i>J. Pharm. Chim.</i>	Journal de Pharmacie et de Chimie.
<i>J. Phys. Chem.</i>	Journal of Physical Chemistry.
<i>J. pr. Chem.</i>	Journal für praktische Chemie.
<i>J. Russ. Phys. Chem. Soc.</i>	Journal of the Physical and Chemical Society of Russia.
<i>J. Soc. Chem. Ind.</i>	Journal of the Society of Chemical Industry.
<i>J. Soc. Dyers.</i>	Journal of the Society of Dyers and Colourists.
<i>J. Tokyo Chem. Soc.</i>	Journal of the Tokyo Chemical Society.
<i>J. Washington Acad. Sci.</i>	Journal of the Washington Academy of Sciences.
<i>Kolloid Zeitsch.</i>	Kolloid-Zeitschrift.
<i>Met. & Chem. Eng.</i>	Metallurgical and Chemical Engineering.
<i>Min. Mag.</i>	Mineralogical Magazine and Journal of the Mineralogical Society.
<i>Monatsh.</i>	Monatshefte für Chemie und verwandte Theile anderer Wissen- schaften.
<i>Pharm. J.</i>	Pharmaceutical Journal.
<i>Pharm. Zeit.</i>	Pharmaceutische Zeitung.

<i>Phil. Mag.</i> . . .	Philosophical Magazine (The London, Edinburgh and Dublin).
<i>Phil. Trans.</i> . . .	Philosophical Transactions of the Royal Society.
<i>Phot. J.</i> . . .	Photographic Journal.
<i>Proc. Roy. Soc.</i> . . .	Proceedings of the Royal Society.
<i>Proc. Roy. Soc. Edin.</i>	Proceedings of the Royal Society of Edinburgh.
<i>Rec. trav. chim.</i> . . .	Recueil des travaux chimiques des Pays-Bas et de la Belgique.
<i>Trans. Faraday Soc.</i>	Transactions of the Faraday Society.
<i>Zeitsch. anal. Chem.</i>	Zeitschrift für analytische Chemie.
<i>Zeitsch. angew. Chem.</i>	Zeitschrift für angewandte Chemie.
<i>Zeitsch. anorg. Chem.</i>	Zeitschrift für anorganische Chemie.
<i>Zeitsch. Nahr.</i>	
<i>Genussm</i> . . .	Zeitschrift für Untersuchung der Nahrungs- und Genussmittel.
<i>Zeitsch. öffentl.</i>	
<i>Chem.</i> . . .	Zeitschrift für öffentliche Chemie.
<i>Zeitsch. physikal.</i>	
<i>Chem.</i> . . .	Zeitschrift für physikalische Chemie, Stöchiometrie und Verwandtschaftslehre.
<i>Zeitsch. physiol.</i>	
<i>Chem.</i> . . .	Hoppe-Seyler's Zeitschrift für physiologische Chemie.

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EXPLOSIVES. Explosives are solid, liquid, or gaseous mixtures or chemical compounds, which by chemical action (set up in them locally by flame, by a blow, or by other means) generate suddenly large volumes of heated gas.

The rate at which the expansive force, which characterises an explosive reaction, is developed, varies considerably, and determines whether the reaction is a combustion, explosion, or detonation. These terms are purely relative, and there is no definite line of demarcation between them.

The factors determining the rapidity of an explosive reaction are the chemical nature of the explosive, its physical condition, the conditions under which it is exploded, and the method of firing.

The energetic action of an explosive largely depends on its rate of chemical change; in chemical compounds (like nitroglycerin and gun-cotton) the reacting atoms are in much greater proximity than are those of a mechanical mixture of solids (such as gunpowder), and in the former class the rapidity of the chemical action will be greater than in those of the latter class, composed of constituents by themselves non-explosive.

Nearly all the explosives in actual use are instances of oxidation, oxygen being supplied by a nitrate, by nitric acid, by an NO_2 group, or by a chlorate or perchlorate.

The oxidising compounds used in explosive mixtures and explosive compounds are frequently endothermic substances, the heat of decomposition contributing towards the expansion of the gaseous products of the explosion. The conditions for complete combustion of the combustible elements do not always give the maximum explosive effect; carbon burning to monoxide gives a larger evolution of gas, but less evolution of heat than on complete combustion, and the best composition for any given explosive effect has to be determined by experiment.

The physical condition of an explosive has a marked effect on its explosibility and the character of the explosion; frozen nitroglycerin

is much less sensitive than the same explosive in the liquid state, nitro explosives that have been fused and cast are less sensitive to detonation than the same explosives in the crystalline or powdered condition, and the same gunpowder mixture gives various effects according to the size of the grain.

Confinement increases the effect of all explosives; the more rapid the explosive the less the confinement necessary to obtain its maximum effect. The power of mercury fulminate is but little increased by confinement, but explosives of the gunpowder type require to be strongly confined to produce disruptive effects.

An explosive reaction may be initiated by a heated solid, a flame, by friction, by percussion, an electric spark or current, or by the concussion from another explosion. The nature of the reaction is largely conditioned by the method of firing adopted; nitroglycerin or gun-cotton in contact with a flame burns quite quietly in the open, but when fired by the detonation of a small initial charge of mercury fulminate, the whole mass of the explosive decomposes practically instantaneously, and detonation results.

The various explosive reactions differ considerably in the amount of impulse necessary for their initiation. To have value as an explosive, a compound or mixture must not be too sensitive to impulse. Substances like nitrogen iodide and diazobenzene nitrate are too sensitive to have practical value. The most sensitive explosives in use, such as mercury fulminate and its mixtures, are used in small quantities in caps and detonators to initiate the explosion of larger masses of less sensitive explosives, propellants or high explosives.

The value of an explosive as a propellant or high explosive depends on its density, on the quantity of gas and heat liberated, and on the velocity of the explosive reaction. For a propellant the gas and heat evolution must be high: for a high explosive it is necessary that all the factors should have a high value.

Explosives may be classified either according to their chemical composition, into explosive

mixtures or explosive compounds; according to their effect and the purpose for which they are employed, into 'high' or 'low' explosives or 'disruptives' and 'propellants'; or according to the danger in handling, transporting, and storing them.

In this article, the chemical classification is adopted, as far as possible. All the substances having explosive properties are not included, but only those that have, or may have, value for practical purposes.

EXPLOSIVE MIXTURES.

In explosive mixtures, the combustible and supporter of combustion are present in separate ingredients, which are usually not in themselves explosive. The necessary speed of reaction is ensured by extremely fine subdivision and very thorough incorporation of the ingredients, and by the oxygen being in a highly concentrated and more or less easily liberated form. An important characteristic of this class of explosives is that their effect may be varied by varying the proportions of the ingredients.

Explosive mixtures may be grouped, according to the source of their oxygen, into nitrate, chlorate, perchlorate, &c., mixtures. Only the mixtures of these oxidising substances with combustible ingredients, in themselves non-explosive, and those containing only a small proportion of an explosive compound added to improve the explosive properties of the mixture, will be considered under this heading. The mixtures of oxidising substances with explosive compounds, where the former are only of secondary importance, will be considered under the respective explosive compounds.

Nitrate Mixtures.

In the nitrates, the oxygen is in sufficiently strong combination to need a somewhat powerful disturbing agency to liberate it, so that the nitrate mixtures are not very sensitive and their action is comparatively slow.

Potassium nitrate mixtures.—Of the various nitrates used in explosive mixtures, the potassium salt is by far the best adapted for the purpose, and black powder, or gunpowder, is the most important member of this class of explosives.

Gunpowder.

Since the introduction of smokeless powders, gunpowder has been gradually superseded for

most military purposes: both as a propellant and a disruptive it is obsolescent. It is still however, very largely used in industrial mining operations, as a propellant for sporting purposes, as a bursting or opening charge for shrapnel shell, and, the smaller sizes, for subsidiary military purposes, such as for primers and igniters for large smokeless-powder charges, for fuses, and as an ingredient in certain compositions.

Ordinary black gunpowder consists of an intimate mixture of potassium nitrate, sulphur, and charcoal. The composition of the black powder used for military purposes in different countries is given in the table below.

English black gunpowders contain about 1 to 1·3 p.c. moisture.

Manufacture.—A short account only of the process of manufacture will be given, mainly that used at the Royal Gunpowder Factory, Waltham Abbey.

The Ingredients.

The nitre employed at Waltham Abbey is wholly Indian nitre. As imported, the 'grough' saltpetre, as it is called, has been partially purified, but contains potassium and sodium chlorides, potassium, sodium, and calcium sulphates, sand, and organic matter; the total impurities averaging about 4½ p.c. It is submitted to a simple refining process, being first dissolved by heat in the water used for washing the purified nitre of a previous operation. The liquid is heated to boiling in large refining coppers, the scum on the surface being carefully skimmed off; the temperature of the liquid is allowed to fall to 104°, and it is then filtered through bags of coarse cloth into the crystallising vessels. The temperature of the solution on entering the crystallising vessels is about 88° to 82°, the liquid is kept in constant agitation with wooden hoes, whereby, as the liquid cools, fine crystals are formed. The solution is not stirred when its temperature is lower than 32°. If the solution were left to crystallise undisturbed, large crystals would form, and would enclose mother liquor. The crystals are drawn to the side of the crystalliser, and transferred to draining frames. The drained nitre flour then receives three washings with distilled water in quantities insufficient to dissolve the nitre, each washing is succeeded by draining; after the last washing the nitre is drained all night, and is removed (except the bottom part, which is very moist) to the store bins. After about three days in store it is ready for the

COMPOSITION OF BLACK POWDER USED FOR MILITARY PURPOSES.

	Per 100 dry gunpowder		
	Potassium nitrate	Sulphur	Charcoal
England, Russia, Sweden, Italy, Turkey, United States .	75·0	10·0	15·0
France, Belgium, Spain, Persia	75·0	12·5	12·5
Germany	74·0	10·0	16·0
Austria-Hungary	75·5	10·0	14·5
Portugal	75·7	10·7	13·6
Switzerland	76·0	10·0	14·0
Holland	70·0	14·0	16·0
China	61·5	15·5	23·0

powder manufacture, and contains from 3 to 5 p.c. of moisture, according to the season; the water is estimated and allowed for in weighing the charges.

The waters used for washing the crystals are employed for the solution of the crude nitre; the nitre is recovered from the crystallisation mother liquors by evaporation, and is treated as crude nitre.

From Désortiaux, it appears that the agitation of the solution of nitre during crystallisation in order to obtain fine crystals is in general use on the Continent; at least, he mentions it as in use at Lille, Wetteren, and Spandau. At the refineries at Lille, Wetteren, and Spandau, he states that glue is added to the boiling solution of the crude nitre (the weight of glue being about $\frac{1}{3000}$ that of the crude nitre); the glue coagulating and carrying down organic colouring matters. The process of purification was the invention of Béaume and Lavoisier, and existing processes follow theirs with slight modifications.

On the Continent, and by most private manufacturers in this country, 'artificial' or 'conversion' saltpetre, or 'German saltpetre,' as it is frequently called, is almost exclusively used. It is made by dissolving 10 parts of sodium nitrate, 'Chile saltpetre,' and 9 parts of potassium chloride, obtained from Stassfurth 'carnallite,' in mother liquors from previous operations, concentrating and crystallisation. It is refined as above.

In 1894 Hellick discovered that 'German saltpetre' frequently contained notable quantities of perchlorate, and it was stated that several accidents in powder factories coincided with the presence of a considerable percentage of perchlorate in the powder. It was subsequently shown that powder containing perchlorate was not unduly sensitive. The perchlorate is, however, not uniformly distributed in nitre, but tends to agglomerate, and the irregular shooting obtained with some foreign sporting powders, as compared with English ones, has been attributed to the contained perchlorate.

The sulphur employed at Waltham Abbey is native Sicilian sulphur, of the best quality. In Sicily, the sulphur mineral is subjected to a liqumation process, to separate the sulphur from the gangue. It still contains 3 to 4 p.c. gangue, from which it is freed by distillation. It is distilled from a large iron retort, provided with two tubes placed at right angles to each other; one tube (15 inches wide) communicates with a large dome-shaped subliming chamber, the other tube (5 inches wide) enters an iron pot which receives the distilled sulphur; this tube is jacketed for cooling with water. The tubes can be connected with the distilling vessel or cut off from it by means of valves. The distilling vessel receives its charge of sulphur, which is heated to boiling; during the earlier stages of the distillation the vapours are sent into the subliming chamber, where the sulphur condenses as 'flowers of sulphur'; later on the sulphur vapour is sent through the condenser, from which it runs into the receiver in the liquid form. It is allowed to cool somewhat, but not to its solidifying point, and is ladled into moist wooden moulds. Sulphur, of sufficient purity to be used in explosives without further treatment,

is now obtained in large quantities, by the 'Chance-Claus' process, from the calcium-sulphide, which is the chief constituent of the residue formed in the manufacture of soda. Much of the sulphur used by private firms and abroad is also obtained from pyrites. The 'flowers of sulphur' are not used in the manufacture of the gunpowder, as they usually contain considerable quantities of sulphurous and sulphuric acids, but are redistilled.

The sulphur igniting in air at a low temperature—about 250°—renders the gunpowder inflammable, and, experience has shown, improves the keeping qualities of the powder. Under the influence of pressure in the manufacturing processes the sulphur flows and becomes colloidal, and cements the particles of the ingredients together. Sulphurless gunpowder is comparatively friable.

The charcoal. For making the charcoal for gunpowder, soft and light woods are chosen, as the charcoals they yield are more readily ignitable, of an average growth of from two to ten years. The wood should be cut in the spring, when it is in full vegetation, as then its bark can readily be removed; in the spring the tree is in fullest sap, but the sap is very watery, and contains but little salts in solution.

At Waltham Abbey, the woods used are: the alder buckthorn (*Rhamnus frangula*, L., improperly called dogwood), alder, and willow (*Salix alba*, L.). Dogwood charcoal is preferable for small-grain quick-burning powders; for powders of larger grain the slower alder and willow charcoals are used. The woods are grown in England, and are cut about four inches in diameter.

Désortiaux states that in France the so-called dogwood (*Rhamnus frangula*) is exclusively employed for making the charcoal for military and sporting powders; he states, however, that it is becoming increasingly difficult to procure, and that they are trying to replace it by willow, or by the wood of the spindle tree. In Germany, 'dogwood' (*R. frangula*), willow, and alder are used; in Russia, alder; in Austria, alder and hazel.

At Waltham Abbey, wood is usually kept for about three years, dogwood in thatched stacks, and willow and alder piled by cords in the open. By the method of carbonisation there followed, 25 p.c. of black charcoal should be obtained from the wood, rather more from dogwood. The wood is cut into three-foot lengths, which are split if differing much in thickness, and is packed into iron cylindrical cases called slips, 3 feet 6 inches long, and 2 feet 4 inches in diameter. The lid is fastened on, two openings (each about 4 inches in diameter) being left in the bottom of the slip. The slips are then placed in horizontal cylinders, the end of the slip with the openings going to the further end of the cylinder, in which end there are openings corresponding with those in the slips.

The cylinders are closed by tightly fitting iron doors, and are built into the wall, with furnaces underneath, so arranged as to admit of the accurate regulation of the heat throughout the operation of charring; this occupies with dogwood about 4 hours for R.F.G., and 8 hours for R.F.G.² gunpowders. The flames surround the cylinder, the heat acting as nearly as possible

on its whole surface. The gases and volatilised tar from the wood pass out through the openings in the slip and the corresponding holes in the retort, into pipes communicating with the furnace in which they are burnt; this saves a considerable amount of fuel. When the wood has been sufficiently charred, which is known by the violet colour of the flame from the burning gas, indicating the formation of carbonic oxide, the slip is withdrawn by means of tackling, placed in a large iron case or cooler, covered with a closely fitting lid, and allowed to remain until all the fire is extinguished, which takes about 4 hours; the charcoal is then emptied into smaller coolers, and sent to store. The charcoal is carefully picked over by hand, to ascertain that it all is properly and evenly burnt, and that no rivets from the slips have broken off. It is then kept from ten days to a fortnight in store before being ground, to obviate the danger from spontaneous combustion (caused by absorption of oxygen from the air) to which charcoal is liable when ground directly after burning.

The smaller the cylinders used, the more uniform is the composition of the charcoal produced, since so high a temperature is not needed to carry the heat to the centre of the charge; in the English powder mills, the tendency has been to use small cylinders, some of which hold only 77 lbs. of wood. The use of small cylinders, however, raises the cost of production (Désortiaux).

Violette states that, for the same temperature, a slow carbonisation gives a much higher yield of charcoal than a quick carbonisation; the percentage of carbon being also a little higher in the former case.

Instead of fixed carbonising cylinders, movable cylinders are now used in most black-powder factories. No 'slip' is used, but two cylinders are provided for each furnace, one being charged while a carbonisation is proceeding in the other. The charged cylinders are run into the furnace on rails, which support them over the fire. An elaborate arrangement for the regular distribution of the gases and products of distillation of the wood is used, by means of which they can at will be directed into any one of the furnaces or allowed partially to escape by the chimney.

The principal advantages claimed for this system are homogeneity of the charcoal, the ready regulation of the combustion of the gases by means of the distribution apparatus, and the cooling down of the charcoal out of contact with the air, which does away with the possibility of the charcoal taking fire.

In some English factories, vertical movable cylinders are used, the advantages being that a larger number can be fired at the same time, and the moving of the cylinders into the cooling room is greatly facilitated.

Böckmann mentions that some years ago the use of rotating cylinders was introduced in Sweden; the cylinders being turned 90° about their horizontal axes every half-hour during carbonisation. It is stated that a more uniform carbonisation is obtained, and fuel saved.

Violette, in 1848, introduced the carbonisation of wood by means of superheated steam. The steam was used at a pressure of $\frac{1}{2}$ to 1 atmosphere, and was raised to the required temperature by being passed through a worm of

wrought-iron heated by a fire. For the production (from dogwood) of *charbon roux* containing 70 p.c. carbon, the temperature of the steam had to be about 280°; by using steam heated to about 350°, charcoal containing 77 p.c. carbon was produced, and by heating both cylinder and steam to a temperature not exceeding 450°, charcoal of 89 p.c. carbon was obtained. The charcoal produced by means of superheated steam is remarkably uniform in composition. The method, however, was abandoned, because it gave a larger yield of *charbon roux*, but not of black charcoal, than the ordinary method of carbonisation in cylinders; and the lightly-burnt charcoal was then only required for sporting powder. Also, the cost of production of the charcoal by the superheated steam apparatus was greater.

Güttler, in 1887, invented a process for carbonising wood, especially cuttings and pulp, straw, peat, &c., in heated CO₂. Carbon dioxide is stated to be preferable to superheated steam, on account of the moist state of the charcoal when cooled in the steam. Gases of combustion, as free as possible from oxygen, are actually used. A producer-furnace is arranged by the side of the charring furnace, in which the CO₂ is produced by blowing air through burning coke by means of a fan. The carbonic acid gas is then blown through a tube into the carbonising cylinder during the carbonising of the wood, &c., and the flow of CO₂ is maintained during the cooling, which in consequence of the presence of the gas may be very rapid.

Composition, &c., of the charcoal.—Carbonising the wood raises the percentage of carbon, diminishing the percentages of hydrogen and oxygen.

Désortiaux states that woods recently cut have almost the same percentage composition; the mean composition of the dried wood being 49.37 p.c. C, 6.14 p.c. H, 43.42 p.c. O and N, 1.07 p.c. ash.

Heintz gives the composition of alder wood minus ash, as 48.63 p.c. C, 5.94 p.c. H, 44.75 p.c. O, 0.68 p.c. N. Peterson and Schödler give alder wood minus ash as 49.20 p.c. C, 6.22 p.c. H, 44.58 p.c. O and N.

On heating, water, carbon monoxide, carbon dioxide, hydrogen, acetic acid, methyl alcohol, and tar are produced.

Violette found that dogwood was converted into slack-baked charcoal (*charbon roux*) at a temperature of 280°–300°; at 300° the yield (on the small scale) was about 34 p.c. and the composition of the charcoal was 73.24 p.c. C, 4.25 p.c. H, 21.94 p.c. O and N, 0.57 p.c. ash. Between 350° and 400°, black charcoals are produced, the yield being from 31 p.c. to 28 p.c., the composition ranging from about 77 p.c. to 81 p.c. C. Between 1000° and 1250°, the charcoal obtained was very black and hard, the yield was about 18 p.c., and the composition of the charcoal 82.0 p.c. C, 2.30 p.c. H, 14.10 p.c. O and N, 1.60 p.c. ash, at the lower temperature, and 88.14 p.c. C, 1.42 p.c. H, 9.24 p.c. O and N, 1.20 p.c. ash, at the higher temperature.

Experiments made at the Chemical Department of the War Department showed no great difference in the specific gravity of charcoals prepared from willow and alder at 394°–558°;

their specific gravity at 15.6° was 1.41 to 1.44. Willow charred at the maximum temperature of 394° for 9½ hours had the composition of 79.22 p.c. C, 4.02 p.c. H, 15.32 p.c. O and N, 1.44 p.c. ash, and specific gravity (at 15.6°) 1.414.

The higher the temperature of carbonisation, the less is the inflammability of the charcoal in air, and the greater the thermal conductivity. Violette states that the charcoals prepared from any kind of wood at 300° take fire when heated in the air to 360°–380°; the charcoals from light and porous woods burning more easily than those from hard and close woods. For the same wood he makes the following statement as to the relation between temperature of charring and that of inflammation in air :—

Temperature of charring	Temperature of inflammation
260°–280°	340°–360°
290°–350°	360°–370°
432°	about 400°
1000°–1500°	600°–800°

The lightly-burnt charcoals are much more absorbent of water than those charred at a high temperature.

The charcoals used for the various kinds of Service black gunpowder range in composition from about 75 p.c. C to 86 p.c. C, according to the nature of the powder. All other conditions being the same (viz. proportion of KNO_3 , S, and charcoal, size of powder, density, and moisture), the charcoal burnt at lower temperatures (having lower percentage of carbon) gives higher muzzle-velocities and pressures than charcoal burnt at higher temperatures and having higher percentage of carbon; that is, for gunpowder of the composition 75 p.c. nitre, 10 p.c. sulphur, and 15 p.c. charcoal. The greater inflammability of the lighter-burnt charcoal makes the gunpowder, of which it forms part, quicker-burning.

The wood is charred to expel moisture, which would lower the temperature of the explosion products of gunpowder, and to obtain a charcoal of suitable inflammability. Charcoal for large-grained powders should be jet-black in colour; for small-grained powders a more slackly burnt charcoal of brown-black colour is used. Before use the charcoal is hand-picked to remove any impurities and any portions insufficiently 'burned.'

Appended is a table of the percentage composition of some charcoals from gunpowders of Waltham Abbey make, and of a sporting powder, which will serve as types of the charcoal used in the different kinds of black gunpowder :—

	W. A. Pebble	W. A. Rifle Large Grain	W. A. Rifle Fine Grain	W. A. Fine Grain	Curtis & Harvey Sporting.
C . . .	85.26	80.32	75.72	77.88	77.36
H . . .	2.98	3.08	3.70	3.37	3.77
O (and N) .	10.16	14.75	18.84	17.60	16.62
Ash . . .	1.60	1.85	1.74	1.15	2.25

(Noble and Abel, Phil. Trans. 1880, 171, 218).

Pulverising, mixing, and incorporating the ingredients.—At Waltham Abbey, the refined nitre is used for gunpowder without being previously dried or ground, but the moisture is estimated and allowed for. The charcoal is ground in a mill; the grinding is done by a cone working in a cylinder, both being suitably toothed. The ground charcoal is made to pass through a spout into a revolving reel of 32-mesh copper-wire gauze, 8½ feet long and 3 feet in diameter, inclined at an angle of about 4° to the horizontal, and making 38 revolutions per minute. The charcoal which passes through the gauze is fit for use, and is collected in a closed reel case; the charcoal too coarse to pass through the gauze falls through the further end of the reel into a vessel, and is reground. The sulphur is ground under a pair of iron edge runners, a smaller-sized incorporating mill, and is sifted through a reel similar to that used for the charcoal. Precautions are taken to connect the sulphur mill to earth, in order to allow the electricity generated by the rubbing of the sulphur to escape, and the machinery is not run rapidly. In some works the sulphur is mixed with a little nitre before grinding to prevent electrification. Besides the danger of ignition by a spark, the electrical charge causes the sulphur to ball together and interferes with the grinding.

The ground ingredients are carefully weighed out in their proper proportions; the largest charge worked in the incorporating mill is 80 lbs. The charge receives a preliminary mixing in the mixing machine, a cylindrical drum of gunmetal or copper, about 2 feet 9 inches in diameter and 1 foot 6 inches wide. An axle bearing 8 rows of gunmetal 'flyers' or fork-shaped arms passes through the centre of the drum; the drum and arms are made to revolve in opposite directions, the former making about 40 revolutions per minute, the latter 120. The mixing occupies five minutes, the mixture being then hand-sifted through an 8-mesh copper-wire sieve over a hopper, to remove foreign substances, which otherwise are liable to cause an ignition in the incorporating mill; the 'green charge' is then tied up in a bag ready for the incorporating mill.

The incorporating mill consists of a circular iron bed, about 7 feet in diameter, very firmly fixed in the floor of the building, on which two iron cylindrical edge runners revolve. The iron runners are 6½ feet in diameter, 15 inches wide, and weigh about four tons. They have a common axle resting in a solid cross-head attached to a vertical shaft, which passes through a bearing in the centre of the bed, and is in gear with the machinery.

The bed has a sloping outside rim. The runners are at an unequal distance from the axis, the eccentricity being equal to half the thickness of a runner; they thus work the charge in the inner and the outer part of the bed, their paths overlapping. The runners are followed by two 'ploughs' of wood, covered with leather, attached to the cross-head by arms; one plough works near the vertical shaft, the other near the rim of the bed, throwing the composition under the runners.

The green charge is spread evenly on the bed of the mill by means of a wooden rake; it is

damp with the moisture of the nitre, but an additional quantity of distilled water (2 to 7 pints) is added from time to time, according to the state of the atmosphere; the moisture assists the incorporation, and the charge is kept not too dry or it would be scattered as dust, not too wet or it would slip away from the runners or cling to them.

The iron runners make 8 revolutions per minute, the green charge is worked under them for 4 hours for R.F.G. powder, for 7 to 8 hours for R.F.G.² powder, and for 3 hours for R.L.G.² and R.L.G.⁴. Dust and reworked charges are worked for 40 minutes.

A drenching apparatus is placed over the bed of each mill, by means of which, in case of an explosion, a tank of water is overturned and the charge drowned. This is done by the action of the explosion gases on a flat wooden lever arrangement, pivoted, and attached to the tank. By means of a horizontal shaft connecting all the levers of a group of mills, an explosion in one mill drowns all the others.

The short radius of the circular path traversed by the runners causes them to take a twisting as well as a rolling motion, and gives them a combined crushing and grinding action very favourable to the thorough trituration and incorporation of the ingredients.

The 'mill-cake,' as the worked charge is called, should have a uniform appearance, and should contain 1 p.c. to 3 p.c. moisture for small-arm powders, 3 p.c. to 6 p.c. for the larger-grained powders. Any 'mill-cake' left firmly caked on the bed is removed by wooden tools after thoroughly moistening. Many accidents have been caused through the use of metal tools.

Breaking down the mill-cake and pressing.

—The mill-cake is next reduced to meal, for convenience in charging the press-box, and in order that the powder may be uniformly pressed: The mill-cake is broken down by means of two pairs of gun-metal rollers, the upper pair being grooved and placed directly above the other pair, which are smooth. The rollers revolve towards each other, dangerous friction from the accidental presence of any hard substance being prevented by one roller of each pair working in sliding bearings connected with a weighted lever causing a pressure of about 56 lbs., so that the rollers would open at any greater pressure. The rollers are fed with mill-cake from a hopper (placed at one end of the machine, below the level of the upper pair of rollers), by means of an endless band of canvas 2½ feet wide, with cross strips of leather sewn on at intervals of about 4 inches. The band passes over a roller at the bottom of the hopper, and over another placed above the upper pair of rollers; on being set in motion it carries the cake from the hopper to a point from which it falls on to the first pair of rollers; the crushed cake then falls on to the second pair, by which it is reduced to meal. It falls into wooden boxes, and is transferred to a magazine ready for pressing.

The meal is pressed into cake by a hydraulic press, fed from an accumulator, the head and bed-plate of which are made of cast iron or cast steel. The powder is pressed between plates about 1 foot 8 inches by 2 feet 4 inches and about

¾ inch thick. Formerly brass plates were used, but now ebonite plates are usually preferred, because they are not so easily bent out of shape, and also because they have sufficient elasticity to transmit the pressure evenly all over the layer of powder, even if they should get out of the horizontal. They have the disadvantage of becoming easily electrified; in fact, alternate layers of ebonite and powder really form an electric pile. To obviate any danger from the possible accumulation of electricity, the presses are provided with an earth connection.

In charging the press, a plate is first put on to the carriage, and round this is placed a wooden frame, deeper than the thickness of the plate. This frame is filled with powder, and the surface smoothed by means of a flat lath, and a second plate placed on the top. The frame is then lifted to the level of the second plate, and the process repeated until the whole charge is made up. A pressure of between 375 and 450 lbs. per square inch is applied, according to the fineness of the powder, the amount of moisture it contains, the state of the atmosphere, and the density required. The pressure is slowly applied, eased off and reapplied several times in order to obtain great density without using excessive pressures: the compression usually lasts from 30 to 40 minutes. A pressure of 375 lbs. per square inch applied for from 1½ to 2 hours produces a cake with an average density of 1·7 to 1·8. The centre of the cake has, however, a greater density than the edges; the edges of the cake are on that account cut away to the extent of about an inch. The amount cut away need not exceed 10 p.c. The centre layers of the pile are slightly less compressed than the top and bottom layers, but these differences in density are partly removed by the subsequent operations. The layers of pressed cake are broken into pieces with a wooden mallet and put into barrels.

Granulating or Corning.—The press-cake is converted into grain by means of a machine consisting of three or four horizontal pairs of gun-metal rollers in a gun-metal frame. The pairs of rollers are placed one above the other, on an axial line inclined at about 35° to the horizontal, the vertical distance between the pairs of rollers being about 2½ feet. For fine-grain powders, the highest pair of rollers has teeth ½ inch apart, the next pair has ¼ inch teeth, and the two bottom pairs have no teeth. Like those of the breaking-down machine, the rollers work in sliding counter-weighted bearings; they make about 25 revolutions per minute. The machine is fed with press-cake from a hopper by means of a moving endless band. Short screens, covered with copper-wire gauze (10-mesh for small-arm powders), are placed under each pair of rollers except the bottom pair, so that the powder too large to pass through the gauze passes on from one pair of rollers to the next. Beneath the short screens are placed two long screens in an inclined position, the upper one of 10-mesh, and the lower one of 20-mesh copper gauze fixed in a frame. A rapid, longitudinal, vibratory motion is imparted to all the screens while the machine is working, to assist the sifting and the flow of the powder. The grain that passes through the short screens will fall through the 10-mesh long screen. That which

is retained on the 20-mesh screen is R.F.G. or R.F.G.² powder; it falls into boxes made to move forward as they are filled. The grains too large to pass through the short screens fall into separate boxes, and are transferred to the hopper to be passed again through the rollers; while the fine powder which passes through the 20-mesh sieve falls on to the wooden bottom of the frame and is collected separately, to be sent back to the incorporating mill for a short re-working.

For granulating R.L.G.² and R.L.G.⁴ powders, three pairs of rollers are usually employed, the two upper pairs with larger teeth, the bottom pair smooth. The grain from the granulating machine is called 'foul grain.' By granulating a gunpowder there is no danger, as there would be with a dust, of segregation of the ingredients during transport according to their densities, the powder is less hygroscopic, there is less danger of escape from storing vessels, and the inflammability and rate of burning of the powder is increased, since the flame can penetrate more quickly through the charge.

Dusting and glazing.—R.F.G. and R.F.G.² powders are freed from dust after granulation by being passed through a dusting-reel. This is a cylindrical frame about 8 feet long and 1½ feet in diameter, covered with 20-mesh copper-wire gauze, and set at a very small angle with the horizontal. The reel is enclosed in a case to catch the dust, but is open at both ends; it is fed continuously at the upper end with powder from a hopper, while the reel makes about 40 revolutions per minute. The powder falls from the lower end of the reel into barrels.

The polish given to the powder grains by glazing is of advantage in diminishing the tendency of the powder to absorb moisture, by breaking off any sharp angles and points, and stopping up the outer pores of the grain, and in enabling it to bear transport without going to dust. Glazing also increases the density of the powder: a powder with a density of, for example, 0.810 before glazing having its density progressively increased to 0.893 after 42 hours' glazing. The small-arm powders, R.F.G. and R.F.G.², are glazed in large drums—cylinders 2 feet wide and 6 feet in diameter (a pair of drums on one axle) making about 12 revolutions per minute. The drums each take about 900 lbs. of powder; they are run 5½ hours for R.F.G., and 10 hours for R.F.G.². No graphite is used for these powders; the friction and heat caused by the motion suffice to produce a brilliant glaze. The glazed powder receives another dusting in a reel covered with 20-mesh wire-gauze, and is then sifted through an 11-mesh sieve into barrels. R.L.G.² powder is run for 1½ hours in drums as above, with about one ounce of graphite per 100 lbs. powder. R.L.G.⁴ is glazed for 3 hours in the old pattern glazing barrels, the same proportion of graphite as for R.L.G.² being added after the barrels have run for 2 hours. Each barrel takes about 400 lbs. of powder; they are 5 feet long by 2½ feet diameter of ends, and make 34 revolutions per minute. The graphite increases the gloss of the powder, and the powder is also rendered less hygroscopic through the increased density of the surface layer.

Stoving or drying, finishing, blending.—The

next operation is drying, which is carried out in a drying-room heated by steam pipes. The gunpowder is placed in wooden frames about 3 feet × 1½ feet × 2½ inches with canvas bottoms, each holding about 12 lbs. of powder, and placed on open framework shelves with which the room is fitted, seven or eight tiers of shelves rising one above another, the steam pipes running under them. The moist air of the room is constantly changed by means of ventilators. At Waltham Abbey, about 50 cwt. of gunpowder are dried at one time. The time and temperature of drying vary with the kind of powder and the amount of moisture in it, the length of time and the temperature increasing with the size of the grain. Thus, R.F.G. requires 1 hour, and R.F.G.² 2 hours at 38°, R.L.G.² 2 hours at 43°, and R.L.G.⁴ 6 hours at 46°. Another system of drying is to drive a current of cold air over steam-heated coils into the drying-room or stove by means of fans. In some factories, a current of cold air is used, after being freed from its moisture by means of calcium chloride, caustic lime, or strong sulphuric acid; and drying at ordinary temperatures *in vacuo* has also been tried. The drying should be done evenly and not too rapidly, so that the pores of the powder are not opened too quickly.

Rapid drying, too, has a tendency to cause the larger-grained powders to crack, and sometimes causes an efflorescence of nitre on the surface of the grains.

The dried powder is *finished* by being rotated in a horizontal reel—a long cylindrical wooden frame covered with canvas, making 45 revolutions per minute—the fine-grain being reeled longer than the large-grain powders. Finishing frees the powder grains from the small amount of dust produced in the process of drying, and gives them (and especially to small-arm powders) a final glaze.

Before drying, and again after finishing, a uniform blend or mixture is made of a large number of barrels of gunpowder. Advantage is taken of every opportunity, in the processes of the manufacture of gunpowder, to mix or 'blend' the grain together so as to obtain more uniform results at proof. This is done by means of a wooden hopper divided into four equal compartments, each able to hold a barrel of gunpowder; the compartments can be emptied simultaneously into a central shoot by means of openings with sliding shutters in the bottom of each. This method of blending, especially with the smaller sizes of grain, is found to give batches of powder with very uniform firing results.

Pebble and prismatic powder. These cut and moulded powders are no longer manufactured, as smokeless powder is now used even for guns of the largest calibre, but a short account of them is given, owing to their great historical interest. The use of pebble powder in this country dated from about the year 1865. Rodman had previously shown that in the gun the pressure diminished as the size of the grains of gunpowder increased, and that the velocity of the projectile could at the same time be maintained by an increased weight of charge.

Pebble powders (P, cubes of ⅜-inch; and P², 1½-inch cubes) were used for larger guns than

were the rifle large-grain powders. Up to the formation of the press-cake, the processes of manufacture were, with some variations, the same as for the finer-grained powders.

The *P* powder was cut from the press-cake, which was pressed into slabs of about 15 inches by 30 inches, and of the required thickness. The cutting machine consisted of two pairs of phosphor-bronze rollers, having longitudinal knife-edges with spaces between them corresponding to the required size of the powder. The first pair of rollers cut the press-cake into strips, which were fed on endless bands to the second pair of rollers, set at right angles to the first, which cut the strips into cubes. These cubes were allowed to fall into a dusting reel, with copper-wire meshes but little smaller than the cubes.

P² powder was cut by hand from the press-cake by means of lever-knives of gun-metal—knives hinged at one end, with a handle at the other. The press-cake was first cut into strips and then across into cubes.

Both *P* and *P²* powders were run in the glazing barrels, by which treatment the edges and corners of the cubes were rubbed down, and a harder surface produced. The powders were then dried at 54°, which required a very much longer time than for the smaller-grained powders; a finishing process followed, the powders being run in wooden barrels with ribs wide enough apart to combine sifting with the finishing glazing. A small quantity of graphite was introduced into the barrels towards the end of the finishing process.

Prismatic powder. This may be regarded as a modification of the perforated cake powder devised by Rodman in 1860. The latter powder consisted of cakes of powder compressed by the hydraulic press, of the diameter of the bore of the gun, and pierced longitudinally with holes of about $\frac{1}{4}$ inch diameter, the cakes being packed in the cartridge so that the holes should correspond. Rodman was led to introduce this form of powder by the consideration that, with solid grains of gunpowder, the surface undergoing combustion in the gun diminishes as the combustion proceeds, and that consequently the strain on the gun is greatest in the earlier stages of the combustion. In the case of the perforated cake gunpowder, as the combustion progressed in the longitudinal holes, the surface undergoing combustion increased. Rodman's theoretical views were confirmed by experiment, but the liability of the perforated cake powder to break up by carriage or when handled, led to its replacement by much smaller hexagonal prisms with one central cylindrical hole; the prisms used in this country were about 1 inch high, the distance between opposite sides of the hexagon about 1.37 inches, the central hole about 0.4 inch in diameter. They were used for heavy breech-loading guns, and were packed so as to form rigid cartridges.

The prisms were pressed from a moderately large-grained powder granulated from press-cake freed from dust in the ordinary way, but not glazed, and finally dried and blended. The increased density of the powder due to the compression delayed the burning and reduced the initial pressure in the gun.

Brown or cocoa gunpowder. The intro-

duction of this powder was a great innovation in powder making, as it greatly improved the shooting of big guns and allowed the use of guns of still larger calibre than even the black prismatic powder. It was composed of 79 p.c. nitre, 3 p.c. sulphur, and 18 p.c. charcoal per 100 of dry powder, and contained ordinarily about 2 p.c. moisture. The 'charcoal' also was a very lightly baked material, the percentage of carbon contained in it being but little higher than that in the (dry) wood or straw from which it was made.

This powder was used for heavy breech-loading guns in the form of hexagonal prisms, having the same dimensions as the black prismatic powder. The rate of ignition and of combustion of the brown prismatic powder was slower than that of the black, and for equal muzzle velocities of the projectile it produced less pressure in the powder-chamber of the gun than black powder, and gave a thinner smoke than the latter. This was due to the fact that the brown charcoals flowed under the high manufacturing pressure and bound the ingredients into a non-porous mass; black prismatic powder was comparatively porous.

Brown or cocoa powder gives on explosion a greater quantity of heat and a smaller volume of permanent gases than does an equal weight of black gunpowder; but the larger amount of water vapour in the products of explosion of brown powder have an important influence in lowering temperature. The products of explosion of brown powder undergo considerable dissociation at first, thus lowering the initial pressure in the gun, and subsequent recombination, and so giving sustained pressures as the projectile moves along the bore. The more gradual development of the pressure and the reduction of the maximum pressure increased the life of the gun and rendered the use of lighter guns possible.

Sporting powder. Considerable quantities of black gunpowder are still used for sporting purposes. The proportions of the ingredients vary slightly from those used for military powders, in order to produce the desirable qualities of quick ignition and combustion. The ease of ignition of a black powder does not vary much with the composition, but an excess of charcoal quickens, whilst an excess of nitre slackens, the rate of combustion. To increase the rapidity of combustion, a slack-burnt or red charcoal is usually used instead of black. The composition of the sporting powder of several countries is given in the following table:—

Composition of Black Powder used for Sporting Purposes.

	Potassium nitrate	Sulphur	Charcoal
England . . .	75.0	10.0	15.0
France . . .	78.0	10.0	12.0
Germany . . .	78.0	10.0	12.0
Austria-Hungary	76.0	9.5	14.5
Switzerland . .	78.0	9.0	13.0

The powders are of high grade and carefully made by processes practically identical with

those used in the manufacture of military powders. Occasionally there are modifications, such, for instance, as the use of drums instead of mills for powdering and mixing the ingredients, because the charge can be less moist and the mixing more rapid, so that better incorporation results in a given time, with resultant greater regularity in shooting.

Mining and blasting powder. The chief requirements of blasting powder are that it should be cheap, slow burning, and develop as large as possible a quantity of gas at a high temperature. The usual composition of blasting powders in various countries is:—

Composition of Black Powder used for Mining and Blasting Purposes.

—	Potassium nitrate	Sulphur	Charcoal
England . .	75.0	10.0	15.0
France . .	72.0	13.0	15.0
Germany . .	70.0	14.0	16.0
Austria-Hungary	60.0	18.5	21.5
Italy . .	70.0	18.0	12.0
Russia . .	66.6	16.7	16.7

These proportions are by no means rigidly adhered to. Thus, in England, blasting powders varying from the above proportions to—potassium nitrate 65, sulphur 20, charcoal 15,—are made, the proportion of nitre being diminished to make the mixture slower burning, an effect otherwise obtained by increasing the size of the grains or compressing to a higher density. Other compositions especially made for use in fiery mines will be mentioned later under ‘Black powder safety explosives.’

Blasting powder is a large-grained powder, sometimes coated with graphite, compressed into cartridges by means of a hydraulic press. As will be mentioned further on, while the mining powder with low nitre and high sulphur gives on explosion a larger volume of permanent gases, it gives a much smaller quantity of heat than black gunpowder.

Fuse powder. A gunpowder of special quality and constant composition is now manufactured for use in ‘safety’ and other fuses. Formerly, siftings from mining powder were frequently used, but this caused unevenness in burning and was frequently the cause of accidents through ‘hang-fires.’ It is a meal powder; that is, of very fine granulation, but free from dust.

Suitable mixtures, determined by trial, of slower and quicker burning powders are made to give the correct time of burning in the time-rings of shell fuses.

Bickford’s safety-fuse (Eng. Pat. 6159, 1831) is a time-fuse in the form of a flexible cord or cable which fits into the metal cases of the detonators used for initiating the explosion of cartridges or other masses of high explosive. It consists of a continuous and uniform train of specially prepared fine-grained powder enclosed in a covering of jute fibre, this core being contained in a tube of waterproof composition and tape, or sometimes, for use under water, in a metal tube. The rate of burning per unit length varies and is stated with the supply, and it is also liable to alter slightly on storage.

Properties and products of explosion.—The

‘density’ (as determined by Bianchi’s densimeter) of the different kinds of gunpowder mentioned ranges from about 1.67 in the case of R.L.G² to about 1.87 in the case of brown prismatic powder. Increase of density of a gunpowder causes its slower combustion, and (under comparable circumstances) diminishes the muzzle velocity of the projectile and the pressure in the gun.

Increase of the amount of moisture in a gunpowder causes diminished temperature of the products of explosion, and lessens the muzzle velocity of the projectile and the pressure in the gun.

Black gunpowder can be ignited by a blow or by an increase of temperature: it explodes at about 300°. The exploding temperature was taken by heating small grains of the gunpowder buried in the sand of a small deep sand-bath, in which the bulb of a Geissler pressure mercurial thermometer was immersed. Black prismatic gunpowder inflamed at about 290°, brown prismatic at 304°. At a temperature slightly above 100° the sulphur can be completely volatilised out of the powder without inflammation taking place. Violette determined the ignition-point by projecting the powder on to molten tin kept at different temperatures. He found that all classes of gunpowder after powdering fired at from 265° to 270°, and that the firing-point depends but little on the composition, but that the size and shape of the grain and the perfection of the incorporation affected the results; thus, blasting powder in grains fired at 270° and extra fine sporting powder at 320°.

The ignition of gunpowder is more difficult and the rate of combustion diminishes with diminished atmospheric pressure. In an atmosphere maintained at a pressure of about 0.5 inch mercury, gunpowder is not exploded by contact with a platinum wire heated to redness by an electric current; the grains in contact with the wire fuse, and, if the passage of the current be maintained, burn slowly without causing the explosion of the remainder. Under the high pressures produced in a gun when fired, the velocity of combustion of gunpowder very rapidly increases.

The products of the combustion of gunpowder have been examined by several chemists, of whom Gay-Lussac (1823), Chevreul (1825), Bunsen and Schischkoff (1857), Karolyi (1863), Federow (1868), Noble and Abel (1875–80), may be more particularly mentioned.

The investigation of the subject by Noble and Abel is much more complete than the others, and some of their results will be briefly mentioned.

The quantity of heat evolved by the explosion of gunpowder was determined by firing 10 to 26 grams of gunpowder in strong steel explosion vessels of 32 and 119 c.c. capacity respectively, the explosion vessels being surrounded by water in a calorimeter of the usual kind.

The volume of permanent gases produced was determined by exploding in closed steel vessels, having an internal capacity of about one litre, quantities of gunpowder varying in weight from about 100 to 800 grams. The vessels retained the whole of the products of explosion, and were provided with an arrangement by which the gases could be allowed to

escape, and could be collected or measured. The pressure in the vessels was measured by means of the usual crusher-gauge (piston acting on, and compressing, a small copper cylinder) contained in a plug screwed into the vessel.

The pressures in the explosion vessels varied with the density of charge $\left(\frac{\text{volume of powder}}{\text{capacity of vessel}}\right)$.

With a density of charge of 0.3, the pressure observed was about 5 tons per square inch; with 0.7 density, the pressure was about 20 tons; with density 1, the pressure was about 42 tons; and with density 1.2, the pressure was about 56 tons.

The powders experimented with had the following percentage composition; the first three were of Waltham Abbey make:—

Nature of powder	Potassium nitrate	Potassium sulphate	Potassium chloride	Sulphur	Carbon	Hydrogen	Oxygen	Ash	Water
Pebble powder	74.67	0.09	—	10.07	12.12	0.42	1.45	0.23	0.95
Rifled large-grain	74.43	0.13	—	10.09	12.40	0.40	1.27	0.22	1.06
R.L.G.									
Fine-grain	73.55	0.36	—	10.02	11.36	0.49	2.57	0.17	1.48
Sporting powder	74.40	0.29	trace	10.37	10.66	0.52	2.29	0.31	1.17
Mining powder	61.66	0.12	0.14	15.06	17.93	0.66	2.23	0.59	1.61
Spanish spherical powder	75.30	0.27	0.02	12.42	8.65	0.38	1.68	0.63	0.65
Cocoa powder	78.83	—	—	2.04	Charcoal 17.80				1.33

The composition of the solid and gaseous products of the explosion of these gunpowders is given in the following table; the numbers given for the first three powders are the means

of 9 experiments with density of charge from 0.1 to 0.9; the sporting and mining powders had density of charge 0.3, the Spanish spherical, 0.7:—

PERCENTAGE COMPOSITION BY VOLUME OF THE DRY PERMANENT GASES.

—	Pebble	R.L.G.	Fine-grain	Sporting	Mining	Spanish spherical	Cocoa
Carbon dioxide	48.95	49.29	50.62	50.22	32.15	53.34	51.30
„ monoxide	13.63	12.47	10.47	7.52	33.75	4.62	3.42
Nitrogen	32.16	32.91	33.20	34.46	19.03	37.80	41.71
Hydrogen sulphide	2.60	2.65	2.48	2.08	7.10	2.74	—
Methane	0.31	0.43	0.19	2.46	2.73	—	0.31
Hydrogen	2.35	2.19	2.96	3.26	5.24	1.29	3.26
Oxygen	—	0.06	0.08	—	—	0.21	—

PERCENTAGE COMPOSITION BY WEIGHT OF THE DRY SOLID RESIDUE.

—	Pebble	R.L.G.	Fine-grain	Sporting	Mining	Spanish spherical	Cocoa
Potassium carbonate	59.26	61.05	51.88	59.10	41.36	35.66	KHCO ₃ 13.55 K ₂ CO ₃ 64.12
„ sulphate	12.93	15.10	22.71	21.65	0.59	48.55	22.33
„ monosulphide	18.98	14.46	18.16	12.42	37.10	7.72	none
Sulphur ¹	8.08	8.74	6.90	6.45	14.11	7.04	—
Potassium thiocyanate	0.25	0.22	0.13	—	2.95	0.04	—
„ nitrate	0.24	0.27	0.17	0.29	0.09	0.95	trace
Ammonium sesqui-carbonate	0.10	0.08	0.05	0.09	1.78	0.04	trace
Charcoal	0.16	0.08	—	—	2.02	—	—

The cocoa powder gives a completely oxidised saline residue, and the proportion of incompletely oxidised gases is smaller with this powder than with the others.

The quantity of heat (in gram-degree units), and the volume (at 0° and 760 mm.) of the permanent gases, per 1 gram of dry powder, were found by Noble and Abel to be:—

¹ Present in the residue as higher sulphide of potassium.

—	Units of heat	Cubic centimetres Permanent gases
Cocoa	837.0	198.0
Spanish spherical	767.3	234.2
Sporting	764.4	241.0
Fine-grain	738.3	263.1
R.L.G.	725.7	274.2
Pebble	721.4	278.3
Mining	516.8	360.3

It will be seen that the order of decrease of units of heat is that of increase of volume of permanent gases; and Noble and Abel observed that the products of heat-units by gas volume do not differ greatly from a constant value, that this points to the conclusion that the pressures at any given density of charge, and the power of doing work of the various powders, are not very materially different,—a conclusion verified by experiment for the three Waltham Abbey powders, and in a less degree also for the other powders. The total potential energy of gunpowder they estimated at about 340,000 kilogram-metres per 1 kgm. of powder, or a little under 500 foot-tons per 1 lb. This calculation supposes the infinite expansion of the products of combustion, but they estimated the actual energy of gunpowder realised by modern guns as varying from about one-tenth to one-fifth of the total theoretical effect.

The temperature produced by the explosion of gunpowder they estimated at about 2,100° in the case of the pebble or R.L.G. powder, at about 2,200° in that of the Spanish pellet powder (Noble and Abel, Trans. Roy. Soc. 1875, 1880; Nobel, Heat-Action of Explosives: a Lecture to Inst. Civil Eng. 1884).

Debus, in 1882, first showed that potassium disulphide is a product of the combustion of black powder. He considered that the combustion takes place in two stages, at first on oxidation, with the formation of potassium sulphate and carbonate, carbonic acid gas, free nitrogen, and, perhaps, carbonic oxide; and, secondly, a reduction in which free carbon and sulphur reduced the potassium sulphate and carbonate.

Debus also showed that from the percentage composition of the powders fired and the products of combustion, the combustion of the powder, as an end result, could be represented in the form of an ordinary equation, from which the theoretical work obtainable from the powder can be calculated (Debus, *Annalen*, vols. 212, 213, 265, and 268).

Examination of gunpowder.—The powder, examined by the eye, should have a perfectly uniform colour, depending on its composition and a proper amount of glaze. Small white specks on the surface of the grains indicate that the nitre has effloresced during drying. The grains must be compact, not flat, in shape; and their size must be uniform, as tested by sifting; and free from dust, as shown by the powder leaving no mark on running it over a sheet of paper. The grains must be hard and crisp, as judged by crushing in the hand. The thoroughness of the incorporation is tested by 'flashing' a small measured quantity of the powder on a porcelain tile by means of a hot wire. The 'flash' should show but few sparks, and there should be no residual solid matter.

By the density, or real density, of a powder is understood the specific gravity of the grains or prisms, including the air contained in their pores. It is usually determined by the Bianchi densimeter. 100 grams of the sample, crushed, if necessary, but free from dust, are weighed out and transferred to the globe of the densimeter. This removable glass globe is fitted with stopcocks above and below, the upper is attached to an air pump, the lower connected by means of a tube with a vessel of mercury, the density of

which is known, at the temperature, usually 60°F. or 70°F., to which it is adjusted. The lower stopcock is closed, the globe exhausted, the stopcock opened, and the mercury then allowed to rise to the height which the atmosphere will support, the lower stopcock closed again, and the upper part of the apparatus opened to the air by means of the air-pump gauge stopcock. The operations are repeated, the mercury surrounding the powder grains being thus subjected to two atmospheres pressure. The globe is then closed, unscrewed, and weighed. Then if S = density of mercury at temperature of determination, W = weight of globe filled with mercury, and W_1 = weight of globe filled with powder and mercury; density of sample

$$\frac{S \times 10}{(W - W_1) + 100}$$

Hygrometric test.—All kinds of black powder are liable to absorb more or less moisture from the air, depending on the quality of their charcoal and saltpetre. The tendency any powder has to absorb moisture is determined by exposing it for a given time—24 hours for the smaller powders—in a specially insulated box at a recorded temperature, to air saturated with moisture, from a saturated solution of saltpetre. The increase in the weight of the powder, added to its previous moisture content, is taken as a measure of its 'hygrometric quality.' The results are, however, not very reliable.

Analysis.—*Moisture* is determined by loss, on the coarsely powdered sample, after 1 hour at 70°, or preferably by exposure over sulphuric acid until of constant weight.

The *nitre* is determined by extraction with warm water, filtering, and evaporating the solution in a platinum dish. The final washings should be kept separate, as the charcoal has a tendency to come through the filter, evaporated to dryness and again extracted, when the filtrate is clear and is added to the bulk. The nitre is dried at 280°, cooled and weighed.

The *sulphur* is estimated by heating 1 gram of powder in a beaker with strong nitric acid until the action moderates, cooling a little, adding a little potassium chlorate to complete the oxidation, and evaporating to dryness. The residue is treated with strong hydrochloric acid, and again evaporated to dryness. The residue is taken up with water (any insoluble matter, grit and graphite, being filtered off and weighed), and the solution precipitated with barium chloride, &c., as usual.

The *charcoal*.—The nitre is removed from the gunpowder by treatment with water, the charcoal and sulphur filtered off, dried, powdered, and treated with carbon disulphide to remove sulphur. The dried charcoal still retains a small quantity of sulphur, which is estimated by the method given above, after the charcoal has been dried in hydrogen in the same manner as for a combustion. The weight of sulphur is, of course, deducted from the weight of charcoal used for the combustion. About 0.5 gram of charcoal is taken for combustion; it is dried (in the boat in which it is to be burnt) by heating for 15 minutes to 170°, in the case of a black charcoal, in a current of hydrogen. The charcoal is allowed to cool in the current of hydrogen, and is transferred to an air-pump

receiver, which is then exhausted. The boat with the charcoal is weighed in a closed tube. The combustion is made in oxygen, a length of granulated copper oxide, maintained at a red heat, being in front of the boat; and in front of the oxide of copper is a shorter length of lead chromate, heated to very low redness to absorb SO_2 or SO_3 ; in other respects, the combustion is made as usual.

Other Potassium Nitrate Mixtures.

Sulphurless gunpowder of various compositions has frequently been tried for special purposes, but without much success. Sulphur renders a powder easy of ignition and increases its rate of burning, and its inclusion is practically essential. Sulphurless powder, moreover, has a tendency to crumble to dust on storage or handling.

Antimony sulphide has been proposed as a substitute for sulphur in black powder, but it is only in certain detonating compositions that it is actually used.

Many combustible substances, amongst others coal, coke, peat, sawdust, bark, bran, tan, sugar, starch, dextrin, gum, hydrocarbons such as paraffin and naphthalene, ferro- and ferricyanides of potassium, tartaric acid, Rochelle salt, sodium acetate, &c., have been proposed and patented as substitutes for all or part of the charcoal in nitrate mixtures. Many of these substances are substituted in order to reduce the amount of smoke. They almost invariably reduce the inflammability of the powder, slacken its combustion, and leave a large amount of residue, but frequently give off larger quantities of gas. These mixtures were suggested principally as blasting explosives, and many were authorised for manufacture in this country, but at the present time their use is practically confined to the Continent.

A few of these explosives will suffice:

Fortis was a mixture of nitre, tan, and sulphur, with small quantities of iron sulphate and glycerol, and it was claimed that nitroglycerin was produced during explosion in a blast hole, with consequent increase of power.

Carbonite, as introduced by Hellhoff of Berlin, was a mixture of nitrobenzene, potassium nitrate, sulphur, and kieselguhr; said to be plastic enough to fill a bore hole, to be non-explosive by blows, when inflamed to burn away quietly without explosion, and when detonated to have the same explosive force as kieselguhr dynamite. It has been used in coal-mines in Germany, but modern carbonites contain nitroglycerin, and are mentioned under 'Dynamites.'

Carboazotine was a mixture of nitre, lamp-black, sawdust, and sulphur, with a little iron sulphate. This explosive required compression into cartridges before it would explode.

Petrolite, as manufactured in Hungary, is a mixture of nitre, wood pulp, coke-dust, and sulphur.

Jahnite, as made in Austria, is a mixture of nitre, lignite coal, and sulphur, with very small quantities of picric acid, potassium chlorate, and calcined soda.

Amidogène, a similar mixture to the last, contained nitre, charcoal, bran, or starch, and sulphur, with a little magnesium sulphate. This

powder had a very slow rate of combustion, but developed large quantities of gas. It was used on a large scale for blasting operations at the Iron Gates on the Danube, and in coal-mines.

Black Powder Safety Explosives.

Ordinary black gunpowder is unsuitable as a blasting agent for use in fiery mines, and its use is everywhere prohibited for this purpose. Many modifications of gunpowder have been tried, and several mixtures have been manufactured which were able to pass the official tests. A few of these mixtures are:—

Argus powder, which contained 81 p.c. potassium nitrate, 18.5 p.c. charcoal, containing 30 p.c. of volatile matter, and 0.5 p.c. sulphur.

Earthquake powder, which contained 79 p.c. nitre, and 21 p.c. charcoal, containing 56 p.c. volatile matter.

Elephant-brand powders, which had the composition of ordinary gunpowder, but No. 1 was fired with 6 inches of ammonium oxalate, and No. 2 with 6 inches of sodium bicarbonate, in front of the cartridge.

Oxalate blasting powder, which was composed of 71 p.c. nitre, 14 p.c. charcoal, and 15 p.c. ammonium oxalate.

All these explosives were subsequently removed from the 'permitted' list.

Bobbinite, manufactured by Curtis and Harvey, is still on the 'permitted' list, and was the most extensively used of all safety explosives in this country in 1913. It is really a high-grade gunpowder, containing but little sulphur, with added ingredients to increase the safety. As originally made, it consisted of 64 p.c. nitre, 2 p.c. sulphur, and 19 p.c. charcoal, with 15 p.c. of a mixture of ammonium sulphate and copper sulphate. In a later composition the mixture of ammonium and copper sulphates was replaced by 8 p.c. of starch and 3 p.c. of paraffin wax, the other ingredients being correspondingly increased. The mixture is compressed into pellets, which are coated with paraffin wax.

Bobbinite is safe to handle, and is fired without detonators; it is slow burning, and does not break up the coal so much as most safety explosives. A Home Office Committee was appointed in 1906 to investigate the alleged danger of 'bobbinite' in fiery mines, but it concluded that these fears were groundless, and the manufacture and use of the explosive was still permitted. The committee also concluded that the damage with 'bobbinite,' as with other explosives, was greater when the shots were not efficiently stemmed. It was the only powder of this class to pass the Woolwich test for 'Permitted Explosives,' but it afterwards failed in the more severe Rotherham test, and in 1914 its use was restricted to mines that were not fiery.

Sodium Nitrate Mixtures.

Sodium nitrate has a higher percentage of available oxygen than potassium nitrate, and is also cheaper, but its hygroscopicity is a great drawback to its use in powders intended for keeping a long time. In dry climates the sodium nitrate powders, made as required for consumption, have been used, as they effect a saving, and are more powerful than the corresponding nitre mixtures. A sodium nitrate mining powder was