A HANDBOOK

ON

MODERN EXPLOSIVES

BEING

A PRACTICAL TREATISE ON THE MANUFACTURE AND APPLICATION OF DYNAMITE, GUN-COTTON, NITRO-GLYCERINE, & OTHER EXPLOSIVE COMPOUNDS, INCLUDING THE MANUFACTURE OF COLLODION-COTTON

BY

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With about One Hundred Illustrations

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PREFACE.

FOR over four hundred years the science of Explosives remained *in statu quo*. Chroniclers record the name of a Franciscan friar—one Berthold Schwartz, of Freiberg—as the inventor, in or about the year 1328, of what has since been known as Gunpowder; although many records are in existence which indicate that prior to that date the Arabs knew the use of an explosive mixture which they called *Medfaa*. This consisted of—

10	drachmas	of	saltpetre,
2	,,	,,	charcoal, and
1½	,,	,,	sulphur;

and it is noteworthy that these proportions closely resemble those of the present formula of English gunpowder—namely,

74·07 saltpetre,
14·82 charcoal, and
11·11 sulphur.

To whom the credit really belongs of inventing gunpowder is so far not cleared up, but there is no doubt that explosive mixtures existed and were utilised by the Chinese as far back as the beginning of the Christian era.

The first advance leading to the introduction of the modern High Explosives was made in 1832 by the

French chemist, Barconnot, of Nancy, who discovered that "when starch, fibres, and analogous substances are acted upon by concentrated nitric acid, they are changed into highly combustible materials." In 1838 Pelouze continued these researches, and he ascertained that this new inflammable material—which he called *Xyloidine*—took fire at 180° C. when submitted to strong pressure, such as a rapid blow. He also found that cotton, paper, and indeed all vegetable matters, could be employed in the preparation of similar substances. All these researches, however, were without any practical value until Schönbein, of Bale, in 1845, devised methods for the manufacture of a new explosive on a commercial scale by treating cotton with a mixture of nitric and sulphuric acids. Schönbein, therefore, may be considered as the inventor of what English-speaking people call Gun-cotton; the Germans, *Schiessbaumwolle;* the French, *Fulmicoton*, or *Pyroxyle*—whence the generic name Pyroxyline.

It is also interesting to note that soon after—in the year 1847—the Italian chemist, Sobrero, discovered in Pelouze's laboratory in Paris the explosive properties of Pyro-glycerine or Nitro-glycerine; but the discovery remained without practical application until 1860, when the Swedish engineer, Alfred Nobel, devised methods for the manufacture of the substance on a large scale, and also succeeded in exploding it with certainty when under confinement. He patented it under the name of Nobel's Blasting Oil; and subsequently he discovered the ready means of absorbing the oil in porous substances, thereby producing the now famous Dynamite or (as it is called in America) *Giant Powder*.

The great benefits which have been conferred upon the world at large by the invention of these explosive compounds need not be expatiated on here. From the first introduction of dynamite into mining operations I fully appreciated the great boon which had been conferred on the mining community by the application of this substance, and I studied its properties and effects with great interest. The result was the appearance in New York, in 1884, from my pen, of the first English treatise on the subject, under the title 'The Modern High Explosives,' published by Messrs. J. Wiley and Sons.

In bringing out this further treatise on the same subject, I have had in view the many discoveries of new compounds which have been made during the last few years, and their application to other than mining uses. A new group of compounds—the fundamental idea of which is due to Sprengel—has now been brought into existence; and these may prove very beneficial to coal-miners in particular, if their *flameless* character should be verified by prolonged use and experiment.

In the following pages I have restricted myself to the outlines of the manufacture of the various nitro-glycerine compounds and varieties of gun-cotton, but I have added some particulars of their physical and chemical properties, and also a condensed account of such modern explosives of other types as are now manufactured in different parts of the globe.*

In the adaptation of modern explosives as propelling agents in guns and for use in artillery, a great deal has already been accomplished, but much remains to be

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* For the name and composition of all explosives now known to be in use or patented, I may refer the reader to Major Cundill's 'Dictionary of Explosives,' from which I have the Author's permission to make the extract quoted by me at p. 50.

done. If one considers the short space of time, barely exceeding twenty years, since the modern explosives were brought into general notice, one must confess that the strides made in adapting them to new uses have been great indeed.

As to their application in the removal of obstacles which nature has placed in the way of the engineer, I have attempted only to give some simple rules and regulations for their safe and successful manipulation, and to show the beneficial results which are derived from their use in the hands of practical men.

How terrible an agent of destruction an explosive may become is seen in the new Pneumatic Dynamite Gun, which is capable of firing 600 lbs. of nitro-gelatine. There is no ship afloat to-day which would be able to resist the explosion of such a charge. Let us hope, however, that modern explosives may find their exclusive employment in the grander and more useful field of operations provided for them by the civil and the mining engineer.

In the preparation of this volume I have tried to avoid, wherever possible, the repetition of matter included in my American work, but it will be readily understood that in certain cases such repetition could not be avoided—for example, in the rules which are laid down for the preparation of bore-hole charges. In this case, also, a few of the sketches included in the former work have been reproduced.

In an Appendix I have given the principal results of the labours of Captain Hess, of the Austrian military service, in the analysis of the various modern explosive compounds. Coming from so distinguished an authority on the subject, the particulars here afforded cannot fail to be acceptable to the English reader. I have also set out the instructions issued by the English Home Office (1) for instituting tests for explosives, and (2) in regard to applications for inclusion in the list of Authorised Explosives; and I have added an abstract of the principal provisions of the Explosives Act, 1875, which has been prepared at my request, and which will be found useful by all concerned in the production and sale, or the use, of explosives.

* * * * *

In the body of the work, I have indicated in several instances the particular sources to which I have been indebted for useful information and material. Here, also, I desire to acknowledge my obligations to the published writings of the distinguished Head of the Chemical Department of the War Office—Sir Frederick Abel, C.B., F.R.S., D.C.L.—appearing in the *Transactions of the Royal Society* and elsewhere: and to various German, French, and American publications which I have consulted—including Dr. J. Upman and E. Meyer's *Das Schiesspulver, die Explosivkörper, und die Feuerwerkerei; Dingler's Polytechnisches Journal; Jahresberichte;* Dr. Guido Wolfram *Ueber Nitroverbindungen der Cellulose;* Roux and Sarrau's *Force et Travail;* Berthelot's *Sur la force de la poudre*, etc. etc.; the *Encyclopædia of Chemistry* (Lippincott, Philadelphia); papers by Professor Munroe in the *Proceedings of the United States Naval Institute* (Annapolis, 1886); Lieutenant Quinan's *Report on Vigorite Powder*, etc., etc.

* * * * *

In the absence of any similar work on the subject in this country, I sincerely trust that the mining community of England and the Colonies will find in these pages sufficient information for their practical assistance in the selection and handling of explosives—a subject of vital importance to the large and increasing number of persons who are interested in mining operations.

17, Belsize Crescent, South Hampstead.
September, 1889.

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A HANDBOOK
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CHAPTER I.

CHARACTERISTICS OF MODERN EXPLOSIVES.

EXPLOSIVES Defined—Progress made in their Manufacture—Their Mode of Action—Several Grades required—Downward Force of Explosives—Springing or Chambering Holes.

THROUGHOUT the following pages I shall use the term "Explosives" for the Modern High or Strong Explosives, in contradistinction to the term "Powder," by which is meant a Low Explosive, such as Gunpowder.

In no department of human industry has more rapid progress been made of late years than in explosives. Their rapidly extending use for the removal of masses of rock has directed attention to their nature and mode of action; and has also led to numerous attempts to increase their effectiveness, to modify their action to suit their different uses, and to reduce their danger.

The ablest chemists and the best engineers have found in the study of explosives a fruitful field; and the results of their labours are to be seen in the perfected explosives of to-day—explosives which are marvels of chemical perfection; which are so modified and varied in their method of action as to be adapted to all varieties of practical work; and which, with all their enormous power, stored up in their particles, are so completely under control, that they may be handled freely in any class of work with perfect safety, when in the hands of careful and experienced operators.

The advantages of using *strong explosives* are manifold and manifest. So obvious, indeed, are they, that explanation would hardly seem to be needed. If of two explosives of equal price, one be stronger than the other, it is evident that less may be employed to do the same work. But economy, as the consequence of strength, is to be sought mainly in another direction; and the principal economy in the use of strong explosives remains, even where the stronger commands the higher price. For, as every practical man knows, the cost of the explosive in blasting operations is small in comparison with the cost of the labour employed. In other words, the main expense of blasting is the labour of drilling, loading, &c.—the cost of the explosive being one of the minor items.

If therefore by using the stronger explosive (even at a higher price) we can accomplish more with the same amount of labour, we shall find that true economy lies in the use of this explosive.

The completion of the work in a shorter space of time must also be taken into account. For, if we wish to complete a work in order to obtain a profit, the sooner the work is completed the sooner we shall commence to realise the profit.

Strength, however, is not the only merit of an explosive. In many cases, indeed, it is a matter of secondary importance; and in certain classes of work the *mode of action*—always a very important point—becomes the paramount consideration.

If we take two explosives, one of which will exert a very powerful action upon a small surface, while the other will throw a milder but more sustained action upon a larger mass, it is evident that both explosives will be useful, each in its own way. The one will exert a shattering force; the other will produce a rending action.* Experience has shown that we need both of these explosives, each for its own work.

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* See my work on 'Modern High Explosives,' pp. 240 to 251, "Force and Effect of Explosive Bodies." J. Wiley and Sons, New York.

If we have to deal with hard rock, and desire, therefore, to exert great force upon a small surface, we shall find economy in the use of the strongest grade of explosives, or No. 1. But if we have to do our blasting in a softer material, we shall find that No. 1 is too local in its action, and that we can break a larger mass with a weaker or slower explosive, or No. 2. Hence, we shall here use No. 2, as giving the most economical results.

The relative cost of the two explosives need not be considered; as a general rule, *it pays* to have explosives adapted to the work, without regard to the small difference in cost.

The custom, which still prevails in some European countries, of using one grade of explosives for all work indiscriminately, is open to serious objections: explosives ought to be modified so as to suit the character of the rock which they have to break down.

Still another mode of action is in many cases desirable—a heaving action, similar to that of black powder or gunpowder, but many times more powerful. It is important, however, that this excess of power should be exerted in breaking up a larger quantity of rock, and not in throwing an equal quantity to a great distance.

As compared with black or common gunpowder, for stoping and for work in light ground, the advantage of a still weaker explosive—such as a No. 3—is obvious, from the fact that smaller holes may be used, and consequently much less labour required in drilling. For instance, if an ordinary compressed gunpowder-cartridge, such as is used for coal mining—say 16 inches long by 2 inches in diameter—is required to break down two cubic yards of coal, and we can store the same amount of energy (which means work) in the cartridge of an explosive No. 3, which is 8 inches long and 1 inch in diameter; the miner, instead of drilling a 2-inch bore-hole, needs only to drill a hole of 1 inch diameter, thus saving both labour and time, or the equivalent in money.

Moreover, the force of black powder, especially in seamy rock, escapes at every crack, and thus much is wasted, as thousands upon thousands of miners will testify. On the contrary, the No. 3 explodes instantaneously and perfectly, and thus the whole force is utilised, no matter how shelly the rock may be.

Every miner knows the importance of having *as much as possible of the charge at the bottom of the bore-hole:* it is there that the maximum amount of work is exerted; and as the explosives contain the stored-up energy in a smaller volume than the ordinary gunpowder or blast powder, they allow of the concentration of the charge nearer the bottom of the bore-hole. Let us suppose two bore-holes, each 1 inch in diameter, and say 6 feet deep. We charge the first hole with gunpowder to a depth of 4 feet, and give it 2 feet of tamping; we charge the second hole with No. 3 explosive to a depth of 2½ feet, and give it 3½ feet of tamping: then "fire" both charges. It will be found that the second hole has given far better results, for the reasons above stated.

The *downward force* exerted by explosives is surprising. This is a benefit in most blasting operations, but its advantage will be specially recognised by those who practise springing or chambering of deep holes.

In deep bore-holes, when it is a question of removing large masses of rock—as in quarrying stone, or in railway cuttings—the practical miner has always recognised the importance of concentrating his charges in the bottom of his bore-holes, and the introduction of explosives has enabled him to produce capacious chambers in the bottom of his bore-holes wherein to lodge his charge. I am a strong believer in "springing" or "chambering" holes, and consider that in the future it will be more largely practised than at present. By its means a small hole is converted into a larger one, and thereby much labour is saved.* Both No. 1 and No. 2 explosives are admirably adapted for springing, but the enormous strength of No. 1 fits it specially for this work. Experiments have shown that it springs a larger "pot-hole" than No. 2 when

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* See 'Modern High Explosives,' *art.* "The Big Mole of the Central Pacific Railway at Oakland."

used in rock. In soft or medium ground many experienced blasters use No. 2 with excellent results.

Every expert at blasting has his own method of doing this work. Nevertheless I give the way which has afforded me the best results. Pack a small quantity of No. 1 or No. 2 explosive, according to the nature of the ground, firmly in the bottom of the hole. Now, lower upon it a small primer, being sure that the primer is well in contact with the charge. Pour in a handful of dry sand, to exclude the air; then explode.

By this means the hole at the very bottom becomes enlarged and fissured, and a large volume of powder or explosive can now be packed *well down* into it, where it will do the most good. It is wonderful how much better execution powder will do when packed in this way in the *very bottom* of the hole.

CHAPTER II.

ATTEMPTS AT SUBSTITUTES FOR GUNPOWDER.

EMPLOYMENT of Nitrate of Soda in Blasting Powders—Barium Nitrate — Potassium Chlorate Mixtures—Picrates—Experiments of Designolle, Abel, and Barbe—Dynamite Gun—Gun-cotton—Sprengel Explosives.

ATTEMPTS to replace gunpowder as a mining and blasting agent, either by modifications of that material prepared with a view to economy, or by explosive mixtures more violent in their action, have been very numerous; few, however, have so far resulted in any permanent success.

The substitution of the comparatively cheap **Sodium Nitrate** for saltpetre, as in the blasting powders of *Oxland*, *Davy*, *Schwarz*, and *De Tret*, has been to some extent successful, though the hygroscopic character of that salt constitutes an insuperable difficulty to the production with it of any but comparatively weak powders.

Barium Nitrate has also been substituted for saltpetre, in the so-called *Saxifragin* powder manufactured by *Wynants* of Brussels, which was originally devised exclusively for industrial purposes, but was afterwards proposed, though without result, for use in heavy guns, on account of the comparatively gradual development of its explosive force. Charcoal has been partly or entirely replaced in powder by other artificial varieties of
bon, and also by organic substances more or less rich in
en. It has been proposed even to use wood fibre
tead of the carbonized product.

Chlorate.—But the chief direction which
ce useful powder substitutes has taken is

that of applying the comparatively violent oxidising properties of potassium chlorate. It has been proposed by not a few inventors to substitute this salt, partly or entirely, for saltpetre in mixtures similar to gunpowder; and numerous preparations consisting of the chlorate more or less intimately mixed with oxidisable substances, both mineral and organic, have been experimented with, and in a few instances have received some amount of practical application. So far, however, no perfect preparation, such as would suggest to the practical powder-maker a good preparation, has come under my notice: they are mostly rough mixtures of chemicals; but no doubt, one of these days, some inventor will be able to produce a good and perfect chlorate of potash powder.

Among those preparations which are best known are the modifications of the original white or German gunpowder—that is, mixtures of sugar and prussiates of potassium with the chlorate, as made by *Reveley;* or preparations consisting of mixtures of tannin, powdered nut-galls, or cream of tartar, with the oxidising agent, as devised by *Horseley*, *Ehrhardt*, *Sharp* and *Nisser;* others, such as *Teutonite*, consist of a small proportion only of the chlorate, mixed with sulphur and metallic sulphides, containing perhaps also free sulphur. Exceedingly crude mixtures of spent tan or sawdust, with saltpetre or other oxidising salts, together with a little sulphur, have been devised apparently rather with a view to comparative safety, than to compete in effects with gunpowder (though the power of victorious competition has been claimed for some): *Kellow's Powder*, *Pyrolithe*, and *Pudrolithe* are preparations of this kind. Lastly, picric acid in the form of the potassium and ammonium compounds, mixed with oxidising salts, has been made the basis of powerful explosive agents, with which experiments (to be described hereafter) have been carried on in England; and lately *Melinite*, which is a picrate compound, has been adopted, with some modifications, by the French Government for the filling of shells: but the exact composition of this French preparation has, so far, been kept secret. A substance called *Lydite* is now being experimented with by the English Government, which no doubt bears much resemblance to the French melinite.

The potassium salt, when intimately mixed with the chlorate, furnishes a product which in susceptibility to detonation and violence of action more nearly resembles nitro-glycerine and gun-cotton than any explosive mixture composed of solid substances, but hitherto it has not been made applicable to practical uses on account of the great readiness with which it is exploded by friction and percussion. Whenever inventors can so modify the composition of the chlorate mixtures as to reduce their sensitiveness, a most valuable ingredient will be available in the manufacture of explosives. Indeed, chlorate of potash seems by its nature destined to play an important part among explosives, as it possesses all the necessary properties of strength and absence of injurious fumes; but we have first to learn how to control it and to confine it within definite bounds. No doubt modern chemistry will furnish us with the means of overcoming what heretofore has been considered an immovable obstacle.*

Picrates.—Mr. Designolle devoted much attention, some years ago, to the production of safer explosive preparations, containing potassium picrate, for use in artillery and small arms. One of these, in which that salt was mixed with charcoal, saltpetre, and potassium chlorate, was experimented with at Le Bouchet on a considerable scale, with some favourable results, but the experiments were abandoned in consequence of a fearful explosion at a factory in Paris, where a large quantity of potassium picrate was stored. Much more satisfactory results have been obtained in experiments carried on by the British Government with a powder proposed by Sir Frederick Abel, and devised at about the same time by M. Barbe, composed of equivalent proportions of ammonium picrate and saltpetre. This mixture is said to be as safely and readily prepared as gunpowder, is perfectly stable in character,

* See 'Modern High Explosives': "Chlorates," pp. 138 to 140; also "Picrates," pp. 135 to 137.

and is not more susceptible than the latter to explosion by friction and percussion. It has furnished satisfactory results when employed in shells and in submarine mines; the explosive force exerted by it is not greatly inferior to that of gun-cotton and dynamite.

The mere contact of a very crude admixture of metallic oxides or nitrates—notably litharge, lime, and the nitrates of lead and strontium—with picric acid, is sufficient, with the application of heat, to cause detonation, and such detonation will extend to contiguous masses of the unmixed picric acid. The heat first induces the formation of picrates, and its continued application causes their detonation.*

The possibility of replacing gunpowder to an important extent, in its application to ordnance, by other explosive agents, appears at the present time quite feasible, and as a disruptive agent for mining purposes it has already in great measure been replaced by the two modern explosives—*Dynamite* and *Gun-Cotton.* Other nitro-compounds are gradually being brought forward, and a new series of explosives, which we will class under the term of *Sprengel Explosives*, are making their way with some success in the United States of America and also in Europe.

The foremost rank amongst modern explosives is at present occupied by dynamite and gun-cotton preparations, and in the following chapters will be found an account of their manufacture and of their chemical and physical properties. As nitro-glycerine forms the base of the dynamites, this important substance has to be considered first.

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* See the special Report by Colonel Majendie, H.M.'s Chief Inspector of Explosives, on "The Circumstances attending a Fire and Explosion at Messrs. Roberts, Dale and Co.'s chemical works, near Manchester, on the 22nd of June, 1887."

CHAPTER III.

PREPARATION OF NITRO-GLYCERINE.

COMPOSITION of Nitro-Glycerine—Process of Manufacture—Stockholm Dynamite Works — Rudberg's Continuous Process — Pellet and Champion's Method — Continental Dynamite Factories — G. M. Mowbray's Process—Compressed Air Mixing Apparatus at Forcite factories.

NITRO-GLYCERINE was discovered at Paris in 1847 by Sobrero, who obtained it by acting with nitric acid on glycerine, and called it, on account of its explosiveness when the temperature is suddenly raised, *Pyro-glycerine.* At first it was put to no practical use; but later it met with pharmaceutical application, chiefly in America, under the name of *Glonoin.* Its value as an explosive was demonstrated by Alfred Nobel in 1863.

Nitro-glycerine, according to *Williamson,* is either a compound of glycerine, a glycerine of nitric acid, or a glycerine trinitrin; the hydrogen atoms of the three hydroxyls of glycerine being replaced by the radical of nitric acid. Its formula, $C_3H_5N_3O_9$ resolves itself into—

$$\begin{array}{l} CH_2.O.NO_2 \\ CH\ .O.NO_2 \\ CH_2.O.No_2. \end{array}$$

But the nitro-glycerine of commerce is rarely, if ever, pure glycerine trinitrin; it contains, according to *Captain Hess,* more or less quantities of glycerine mononitrin and glycerine dinitrin. Hess found 13·7 to 16·6 per cent. of nitrogen in commercial samples, whilst pure glycerine trinitrin requires 18·5 per cent. of nitrogen.

Nitro-glycerine is formed, as already stated, through the action of concentrated nitric acid on glycerine. The process is represented by the equation—

$$\underset{\text{Glycerine.}}{C_3H_5(OH)_3} + \underset{\text{Nitric Acid.}}{3\,NHO_3} = \underset{\text{Nitro-Glycerine.}}{C_3H_5(O.NO_2)_3} + \underset{\text{Water.}}{3\,H_2O.}$$

By using a mixture of nitric acid and sulphuric acid, the latter binds the water eliminated in the reaction; and by thus preventing a dilution of the glycerine, aids the formation of the nitro-glycerine.

Process of Manufacture.—According to *Sobrero*, two volumes of sulphuric acid, of 1·831 specific gravity, and one volume of nitric acid, of 1·525 specific gravity, are mixed and permitted to cool, and half a volume of glycerine, of syrupy consistency, is then introduced with constant stirring. The mixture is again cooled, not necessarily below 0° C., and, after having become turbid and separated into two layers, poured into fifteen to twenty times its bulk of cold water. The oily nitro-compound sinks quickly to the bottom, is freed from unchanged acid and glycerine by repeated washing with water, and lastly, dried *in vacuo.*

Praeger and *Bertram* use one part by weight of glycerine to eight parts of a mixture of one part of concentrated nitric acid and two parts fuming sulphuric acid.

Liebe recommends pouring one part by weight of glycerine into a mixture of two parts of nitric acid, of 1·525 specific gravity, and four parts of concentrated sulphuric acid; keeping the mixture below 25° C.; and drying the washed nitro-glycerine in the steam bath. Various other methods have been proposed.

In preparing nitro-glycerine on a large scale, the glycerine is obtained from some candle factory; the sulphuric acid, likewise, from some outside works; but the nitric acid is produced on the spot. The nitro-glycerine works must be so placed that, in case of an accident, the destruction should be limited to the factory. The nitric acid is distilled in a compartment by itself. The manufacture of the nitro-glycerine is sometimes carried on in three wooden sheds of light structure separated from one another by strong earth banks, of 25 to 30 feet in thickness at their base; the walls and roofs are lined with straw, and the temperature, by means of hot-water pipes, is kept day and night at 15° C.

In the one shed the glycerine is brought together with the mixture of acids; in the second shed the nitro-glycerine is poured into the water, and otherwise washed; in the third shed the complete elimination of acid from the oily compound is effected, and eventually the nitro-glycerine is worked up into dynamite. These three operations are now usually effected in one building, by means of more modern appliances, but in some of the older factories the above system is still adhered to. The sheds are sunk into the ground, so that their flat roofs are barely above the level of the ground; they are lit up by reflecting lamps placed outside on the roofs; the floor is covered with fine sand. At some distance from these sheds are the huts in which the cartridges are made. They likewise are separated from one another by earth banks, and so is another shed in which the packing takes place. Quite away from all these buildings are the store-houses, sunk into the ground. There are usually also cellars for the keeping of ice, which latter serves for cooling the wash water and the mixing tanks. The storing of the raw glycerine and the sulphuric acid requires no special precaution.

Stockholm Dynamite Works.—*Rudberg* recommended the following process here in 1868. Figs. 1 and 2 show, respectively, vertical sections of front and side views of the apparatus. Vessel 1 contains the acid mixture which had previously been cooled in a vat lined with lead; vessel 2 contains the glycerine; and 3, cold water. All these have outlet tubes which are provided with taps. The contents of 1 and 2 are permitted to flow, on opening the taps *a* and *b*, through the tubes A and B, into the vessel provided with the funnel C; this latter vessel is suspended over the channel D, which is fitted with stair-like shelves, and surrounded by a water-tight wooden trough. According to the arrangement represented in Fig. 1, the vessel receiving the contents of 1 and 2 is not suspended, but is provided with wheels, so that it can be caused to move continuously to and fro on the rails *c*. The lower ends of the outlet tubes A and B are slightly bent, and are situated at the opposite side of the bulb of a thermometer T, placed between them. In this way the glycerine and the acid mixture meet just below the thermometer, and the rise of temperature caused by the chemical reaction can thus be accurately measured. For the sake of greater caution, there is a second thermometer fixed in the tube of the funnel C. The water from 3 enters through tube *g*, by tap *m*, the space between the channel D and the surrounding trough, and finally leaves through tube *n*.

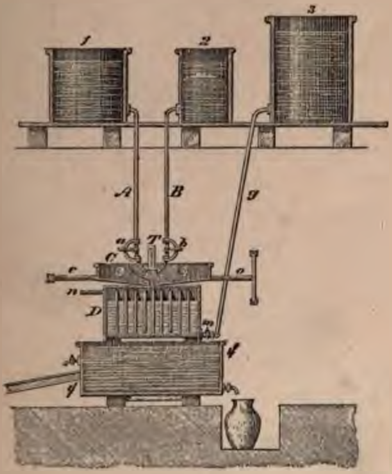

FIG. 1.—RUDBERG'S NITRO-GLYCERINE APPARATUS.

The working of the apparatus is easily understood. The channel D is surrounded with cold water from 3, through *g* and *m*, and now the acid mixture is allowed to flow slowly into the funnel C, which is set in oscillating motion, so that the tube of the funnel should alternately be over the different compartments of the channel D. As soon as the acid begins to run simultaneously from all the compartments, the glycerine is turned on and allowed to mix with the acid. The reaction between the two takes place immediately; it is completed as soon as the mixture has passed through the channel D, which is carefully to be kept cool by a constant supply of cold water. From D the mixture flows into the large vat 4, where

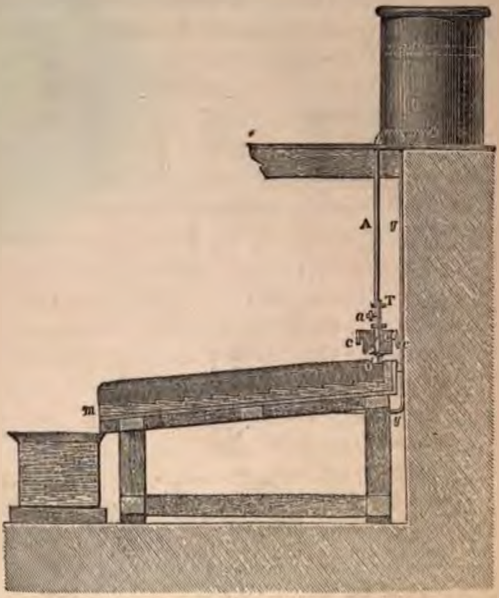

FIG. 2.—SECTION OF RUDBERG'S NITRO-GLYCERINE APPARATUS.

the nitro-glycerine separates as an oily layer. It is drawn off, washed first with solution of sodium carbonate, then with water.

The remaining diluted acid can be concentrated with very little expense, and used again for nitrifying glycerine. If no such re-application of the acid mixture is intended, the vessel 4 is filled with water, whereupon the nitro-glycerine sinks to the bottom, and can easily be separated from this supernatant acid liquid. Washing with sodium carbonate solution and with water concludes the process.

Pellet and *Champion* noticed in 1871, that if the whole quantity of glycerine required in one operation be suddenly poured into the acids, and the mixture stirred with a glass rod for ten seconds, the formation of the nitro-glycerine will have been completed, and yet there has been no time for a rise of temperature to take place; on throwing, therefore, the mixture into a large mass of water, the nitro-glycerine will separate. But the syrupy condition of glycerine makes it difficult to let a quantity of it flow quickly into the acid. Champion recommends, therefore, to allow the glycerine to run down the sides of the mixing vat, so as to accumulate on the surface of the acids, and when the desired quantity is floating above the acids, to mix the two quickly with a glass rod for ten minutes, and then to pour the mixture into fifteen to twenty times its bulk of cold water. Washing with soda and water, and drying by means of calcium chloride, or by heating to 30° or 40° C., conclude the process. The quantity of nitro-glycerine thus obtained is double that of the glycerine used.

Continental Dynamite Factories.—In European factories, where the daily production is two tons and over, the nitro-glycerine is prepared in the following manner:—

The glycerine used is of 1·26 specific gravity. The nitric acid is obtained by distilling a mixture of equal parts of Chili saltpetre and sulphuric acid in cast-iron retorts of about 180 cubic feet contents; it is red from nitrous acid, and contains also chlorine, derived from chlorides in the saltpetre; but nevertheless it can be employed without further purification for the nitrification of the glycerine.

The nitric acid is brought to the specific gravity of 1·48, and 1300 lbs. of this acid are mixed in four cast-iron pans with twice that weight of sulphuric acid; this mixture, which is left to cool for a day, serves for the treatment of 630 lbs. of glycerine. The acid is drawn from the pans into a wooden cylindrical vat, about 6 feet in height and 3½ feet in diameter, lined inside with thick lead, and containing along its lining two spiral lead pipes of about 1 inch diameter, which reach from the bottom to the top. Each of these spirals, or worms, forms a system by itself, through which cold water circulates, and one may serve as substitute for the other in case of leakage of one of the spirals.

The mixture of acids is stirred first by itself in this vat; the stirring is effected by two iron discs, covered with lead—disc and covering being perforated—which glide up and down on a vertical iron shaft, the gliding motion being effected by pulling the rope attached to the discs over a pulley. The two or three workmen who perform this task stand at a distance of 30 to 40 feet from the vat behind a strong earth bank. When the acids have been introduced into the vessel, and the agitation has commenced, water of 6° to 8° C. is let into the worms; the temperature of the acid can be maintained in this way at 14° to 16° C., as may be ascertained from a thermometer which reaches through the lead cover of the vessel into the acid. The glycerine, which is kept in a zinc tank on the roof of the shed in which is the mixing vat, is now allowed to run into the latter vessel. The flow is regulated by means of a tap, and also by letting the glycerine first run into perforated zinc boxes, placed on the lid of the mixing vat, and corking up, if occasion requires, some of the perforations.

As soon as the glycerine falls into the acid the temperature rises at once; but by carefully regulating the supply of glycerine it may be kept at 18° C., or lower.

It is advisable not to allow the temperature to rise above that degree, though experience shows that a higher temperature yields a larger quantity of nitro-glycerine. It requires, according to the season and the temperature of the cooling water, half an hour to two and a-half hours for 630 lbs. of glycerine to pass into the mixing-vat; the stirring must not be stopped for a moment during the process.

When all the glycerine has been added to the acids the mixture is at once drawn off through a leaden pipe to the so-called wash shed, where it passes into a tank about 8 feet high and 12 feet diameter, which is half filled with cold water. The inlet tube carries a sieve, to retain lead sulphate that may have been brought from the mixing-vat. Whilst the nitro-glycerine flows in, stirring with wooden poles is begun, and continued until the nitro-compound has settled below the dilute acid. The bottom of the wash vessel is slightly inclined so as to allow a complete drawing off of the nitro-glycerine. The outlet taps are of stoneware. The nitro-glycerine is now twice washed with water, freed from acid and lead sulphate, and finally washed with water to which some sodium carbonate has been added.

But even after this purifying process there remain traces of acid; to eliminate these the nitro-glycerine is transferred to a third shed, where it is agitated for about an hour in a rotating vessel, called the Butter Machine, with about 50 lbs. of a concentrated solution of sodium carbonate; after this time it will no more redden litmus paper. It is now separated from the alkaline solution, filtered through felt, and collected for further use in leaden reservoirs.

The yield by this method is from 950 to 1200 lbs., according to the condition of the raw glycerine, the concentration of the acids, and the temperature. It is considerably below the theoretically calculated quantity. This shortcoming is due to the formation of glycerides, which dissolve in the wash waters. As a rule, the yield in winter is greater than that in summer.

Mowbray's Process.—*G. M. Mowbray*, whose factory is situate near North Adams in Massachusetts, U.S.A., gives an account* of the process there adopted, from which the subjoined particulars are taken :—

In the first place, the nitric acid is distilled from five retorts, each of them about 100 cubic feet contents, which are placed in a well-ventilated building; each retort receives 300 lbs. of Chili saltpetre, and 375 lbs. of sulphuric acid; the vapours pass through stoneware pipes into a series of four receivers, likewise

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* In his work on 'Tri-Nitro-Glycerine.'

of stoneware, and placed on a bank about one foot above the ground; the first two receivers contain each 150 lbs. of sulphuric acid, the third 100 lbs., the fourth nothing. The sulphuric acid in the receivers facilitates the condensation of the nitric acid vapours, and the mixture of acids required for the nitrification of the glycerine is obtained at once. The distillation is finished after twenty-four hours; the mixture of acids, altogether about 600 lbs., is then drawn off into carboys, and from these emptied into a stone trough, which is capable of holding the contents of 18 carboys. In order to effect a uniform mixing of the acids, and also to remove nitrous gas, a current of air is passed for five minutes through the liquor in the trough.

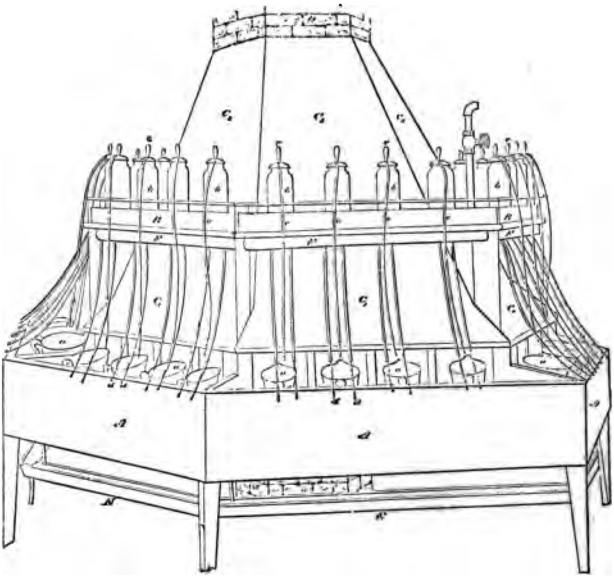

FIG. 3.—MOWBRAY'S NITRO-GLYCERINE APPARATUS.

The nitrification of the glycerine takes place in stoneware jars; 116 of these, *a*, *a*, *a* (see Fig. 3), are distributed over nine wooden troughs, A, A, A, which latter are filled to within a few inches from the top of the jars with ice-cold water, or a mixture of ice and salt. Each jar receives 17 lbs. of acid mixture, and into this 2 lbs. of glycerine is introduced drop by drop from glass vessels *b*, *b*, *b*, which are placed on a shelf B, B, just above the acid jars. Below this shelf runs an iron tube, about 1½ inch wide, through which cold dry air is conducted; from this tube F, F, F, glass pipes *d*, *d* branch off, joined by means of indiarubber tubes, into each jar, which thus receives during the dropping in of the glycerine a constant current of cold air, acting both as cooler and as stirrer. A very beneficial influence is ascribed to this air current, which also oxidises nitrous acid vapours.

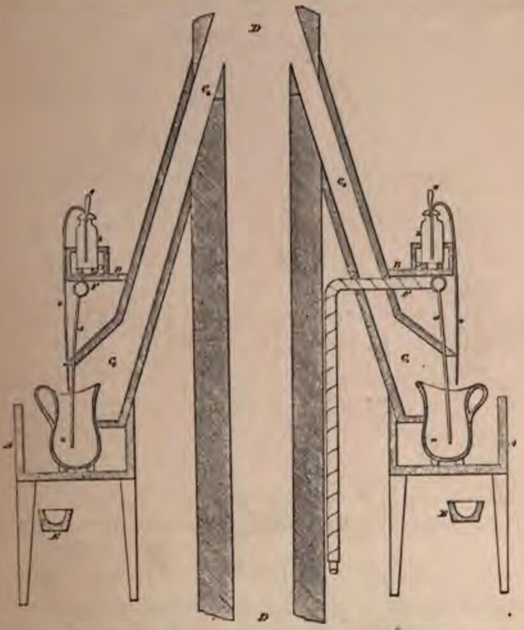

FIG. 4.—SECTION OF MOWBRAY'S NITRO-GLYCERINE APPARATUS.

As there is a large disengagement of nitrous vapours during this process, provision to carry these vapours out of the building is made, by placing the troughs with the pots around chimneys, D, D, Fig. 4, and above each pot *a*, *a*, is a flue C_1, C_2, leading into D, which carries the fumes outside the building.

The nitrating house, in which this operation is performed, measures 150 feet in length.

The introduction of the glycerine into the acid must be finished within an hour and a-half; there should be no rise in temperature, and certainly no appearance of red vapours. After the transformation of the glycerine, the jars are emptied into a large vat A, Fig. 5, containing water of 21° C. or 68° F.; the nitro-glycerine sinks to the bottom and remains covered with about 6 feet of water for a quarter of an hour, when first the water is drawn off from above at faucet b_1, then the nitro-glycerine from below at b_2. The latter is transferred to the oscillating cask B, in which it is washed three times with water, and twice with soda solution, a current of air passing through the liquid all the time. The wash waters pass into a tub, from thence into two casks C sunk into the ground, where such nitro-glycerine as had been carried away by the water is retained.

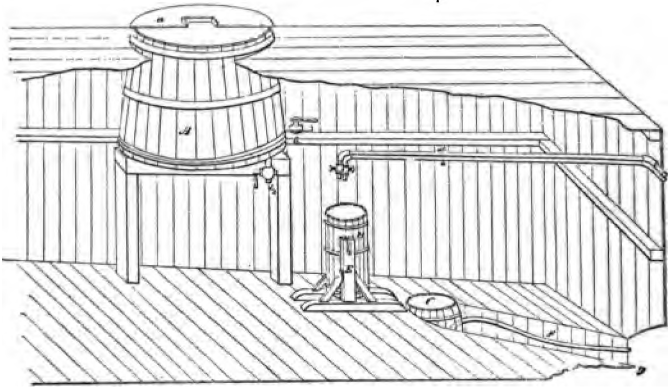

FIG. 5.—MOWBRAY'S NITRO-GLYCERINE WASHING APPARATUS.

The nitro-glycerine is carried in copper vessels to a shed, about 100 yards distant, and poured into stoneware jars, of

60 lbs. contents, and the jars placed in reservoirs filled with water of 21° C., and left there three days. Impurities rise to the surface, and are skimmed off.

The nitro-glycerine is now ready for commerce. It is filled in canisters of galvanised sheet-iron, coated inside with paraffin, and capable of holding 56 lbs.; the floor of the shed where the filling takes place is covered with a thick layer of calcined plaster of Paris, in order that any spilt nitro-glycerine may be absorbed at once. The canisters are then exposed to the cold of ice and salt for the sake of freezing their contents; in this state they are stored, 30 to 40 to a batch, in magazines 100 yards from all the other buildings of the factory. The transport of the nitro-glycerine takes place also whilst it is frozen.

The yield in Mowbray's factory amounts to 223 per cent. of the glycerine employed.

Compressed Air Mixing Apparatus.—At the forcite works in America, Belgium, and Spain, the nitro-glycerine is prepared by means of a mixing apparatus worked by compressed air. In a large vat, lined with heavy sheet lead, the acids are mixed every evening in the proportion of 650 lbs. of nitric acid to 1300 lbs. sulphuric, and left over night to cool. These vats are located under an open shed on high ground, and in the morning they are let flow by gravitation through lead pipes into the nitrating apparatus.

This apparatus consists of a large cylinder made of ½-inch sheet lead, closed at top and bottom and set in a wooden tank, which is larger than the cylinder, so as to leave a space of 2 or 3 inches around its sides and bottom. This space serves as a water-jacket for the continual circulation of cold water outside the cylinder. Inside the cylinder are several coils of 1-inch lead pipes, so arranged that the inlet and outlet of these pipes pass through the top cover. This top cover can be occasionally removed for repairs. There are also two small openings in the top cover for the insertion of long thermometers; one central opening for the insertion of an injector, which is a very ingenious instrument for the admission of compressed air and glycerine, and can be regulated so as to control the flow of glycerine as well as the compressed air. There is also an escape-pipe for the nitrous gas.

When the acids have been charged into this nitro-glycerine apparatus, the water is turned on and allowed to circulate freely through the jacket and coils, which cools the acid mixture. The injector is now connected with the glycerine tank (located on the roof of the building) and with the air receiver by means of indiarubber pipes, and the compressed air agitates the mixture while a small stream of glycerine flows in; when the charge of glycerine, say 310 lbs., has been run in the nitrating process is finished, a large faucet of stoneware is opened, and the contents of the cylinder discharged into another open lead-lined vat located on a lower story of the building.

It must be mentioned that while the glycerine flows into the nitrating apparatus the operator should closely watch the thermometers, and see that the temperature of the mixture in the cylinder does not exceed 28° C. or 80° F. There are special thermometers made for this purpose which have the number 80 marked in red, indicating thereby the danger point. During the manipulation, should the temperature for some cause rise to this point, the flow of glycerine should at once be interrupted, and the influx of compressed air continued; if in spite of this the temperature rises—*let the operator not lose his presence of mind*, but open the discharge faucet and let its contents flow into a large tank placed on the lowest floor of the building, which is always half filled with water. Here the charge is drowned, and all danger of premature explosion is avoided.

If the charge works well it takes about an hour to nitrate 310 lbs. of glycerine, and when the same has been discharged into the lead tank or separator, where it is allowed to remain quietly for a few minutes, the nitro-glycerine, owing to its lighter specific gravity, will collect on top of the acids; there it is skimmed off by means of a dipper as it rises to the surface, and is poured into washing vessels to be freed by repeated washings, first with clear water, and then with solutions of carbonate of soda, from any acid which it may contain. The washing is effected by agitating the water and nitro-glycerine with a current of compressed air.

The acids remaining from the separator are now allowed to flow into a species of tower filled with quartz pebbles, where by a special process the last traces of nitro-glycerine are destroyed, and then the acids are ready for reconcentration and further use.*

Most manufacturers keep the details of their manufacture secret, and it is well to mention here that only those who already possess a practical knowledge of the manufacture should undertake the making of nitro-glycerine.

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* At Nobel & Co.'s works the process for manufacturing nitro-glycerine differs only in small details from the description here given.

CHAPTER IV.

PROPERTIES OF NITRO-GLYCERINE.

Its Physical Properties—Its Effect on the Human System—Decomposition—Gases Evolved—Detonation—Nitro-Glycerine in Use—Accidents when in the Liquid State—Rendered Non-explosive with Methylic Alcohol—Gelatinised Nitro-Glycerine or Nitro-Gelatine.

NITRO-GLYCERINE is at ordinary temperatures an oily liquid, clear, colourless, or yellowish, refracting light, of sweetish and burning taste, without odour, of 1·6 specific gravity. At lower temperatures it becomes solid, the degree at which it solidifies greatly varying. *Champion's* was at —15° C. syrupy, but became solid after continued keeping at —20° C.;* *Mowbray's* solidified at 7·2° C., and contracted by $\frac{1}{12}$ of its bulk; *Abel's* nitro-glycerine became solid at 12·8° C. In water it is insoluble, but it dissolves easily in ether, wood spirit, benzol, chloroform, and hot alcohol.

[illegible] produces serious consequences when taken into the human [illegible], causing vertigo, weakening of sight, stupor, pains in [illegible] [illegible] region; in larger doses it acts like strychnine, [illegible] fatal when more than 10 grains are swallowed. Even [illegible] [illegible] with the skin produces serious symptoms, though [illegible] [illegible] used to it after a time.

Decomposition.—Pure nitro-glycerine does not decompose [illegible] spontaneously at ordinary temperatures, but at higher [illegible] [illegible] nitrous acid vapours are disengaged. It may be [illegible] heated to 100° C., but becomes very sensitive to slight

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* [illegible] [illegible], but this would not have been pure tri-nitro-glycerine.

shocks. According to *Kopp*, it may even be evaporated by being dropped upon a moderately hot plate; but, if the plate is hot enough to bring the nitro-glycerine to boiling, it explodes, according to *Group Besanez*. Experiments of *Champion* have shown that it evaporates at 185° C., boiling and evolving red fumes, burns briskly at 217° C., and detonates with violence at 257° C. I may say that these phenomena may take place at lower temperatures.

The decomposition of exploding nitro-glycerine takes place, as *Berthelot's* researches show, according to the equation

$$2\ C_3H_5\ (ONO_2)_3 = 6\ CO_2 + 5\ H_2O + N_6 + O.$$

Nobel has calculated that one volume of nitro-glycerine disengages 1298 volumes of gases of 100° C. at a barometric pressure of 760 mm., consisting of 554 water vapour, 469 carbonic acid, 236 nitrogen, and 39 oxygen. *List* estimates the bulk of the liberated gases at 1504·9 volumes. Nitro-glycerine evolves, therefore, at the lowest estimate, nearly six times as much gas as gunpowder, computed for a temperature of 100° C.; but a far higher degree of heat is produced by the instantaneous combustion of nitro-glycerine, which, according to Nobel, expands the bulk of the freed gases to eight times the original 1298 volumes, whilst the gases of gunpowder would not be trebled at a like temperature; the explosive force of nitro-glycerine, therefore, stands to that of gunpowder as 13 to 1, according to volume.

Detonation.—Putting a light directly to nitro-glycerine does not lead necessarily to detonation. Poured out in a thin layer, the liquid burns away like gunpowder. A red-hot iron rod, applied by Nobel to nitro-glycerine, had no effect whatever; a burning wooden splinter kindled it to a quiet flame, but, on removing the match, the flame of the nitro-glycerine went out immediately; according to Nobel's experiments, when it is set on fire it will burn away quietly long before it is heated to the degree at which it will explode, but this has never been proven on a large scale, and I would not recommend such an experiment.

It is only on being heated in a closed space that its entire mass explodes, when the temperature reaches 257°. Such a heating can be effected by the electric spark. Sir Frederick Abel placed two poles, connected with a Ruhmkorff coil, into some nitro-glycerine, and allowed a number of sparks to pass between them; the surface of the nitro-glycerine became agitated, turned black, and after half a minute exploded.

Gradually increasing pressure is unable to explode liquid nitro-glycerine; but a sudden blow will do it, though it detonates only that portion with which it came in contact. The explosion produced in the part that had been directly exposed to the blow will not communicate itself to the rest of the nitro-glycerine. If, however, nitro-glycerine is in a solid condition—frozen, for instance—a blow given to a portion will be transmitted at once to the entire mass. Several accidents are on record where the explosion could be traced to some mechanical force having acted on frozen nitro-glycerine. One kind of mechanical force—shaking—seems to form an exception to this observation; for, as already mentioned, Mowbray's nitro-glycerine is safer to move in a frozen than a liquid state, and Nobel also mentions that liquid nitro-glycerine is extremely sensitive to vibration.*

The detonation of gunpowder, gun-cotton, or fulminate, causes nitro-glycerine to explode, whether it is loose or under confinement.

Exposure to the solar rays transforms nitro-glycerine into a very unstable, easily explosible substance; and *Jouglet* observed spontaneous explosions of nitro-glycerine in air charged with ozone. Dynamite loses its strength in tropical countries by gradual evaporation of nitro-glycerine. I have made this observation on the Isthmus of Panama, where dynamite refused to explode after several months' storage.

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* See 'Modern High Explosives': art. "Accidental Explosion at Hoosic Tunnel"—an accident which was the result of vibration.

Nitro-Glycerine in use.—At the first nitro-glycerine was used in conjunction with gunpowder; the latter was exploded by any of the usual methods, and through its explosion the nitro-glycerine was detonated. A tin cartridge was filled first with gunpowder, then with nitro-glycerine, closed by a cork, and placed in the bore-hole, which had to be about a quarter of an inch wider than the cartridge; the space between was filled with coarse-grained gunpowder, which covered the cartridge about an inch high; a fuze was inserted, and the bore-hole tamped with sand. Later a special detonating capsule was used by Nobel, consisting of a wooden box filled with fine powder, and provided with a fuze. The nitro-glycerine was poured directly into the bore-hole, which had to be lined with plastic clay.

In March, 1865, blasting on a large scale was carried out in the granite quarries near Stockholm. A bore-hole of about 10 feet in depth was charged with 5 lbs. of nitro-glycerine; after explosion, about 200 cubic yards of granite, weighing something like 350 tons, were found torn away, and the main rock was traversed by long fissures. This result created much sensation, and caused a great demand for the new explosive. The application of nitro-glycerine increased in the next following years, and amongst other uses, it was soon used for breaking up large masses of old iron, such as anvils, cylinders, &c.

The efficiency of nitro-glycerine in water was shown by experiments which Nobel performed in 1866 in a pond near Hamburg. A canister, containing about 2½ lbs. of nitro-glycerine, was lowered under the surface of the water and fired; the explosion sent up a column of water of about 9 feet in diameter to a height of about 300 feet. A like quantity of gunpowder in a similar canister, on firing, lifted the water to no more than a few feet.

The highly favourable reports on the explosive value of nitro-glycerine were soon followed by statements of its being one of the most dangerous of known blasting agents. In 1866 a West Indian mail packet was blown up, a wharf torn down, a number of adjacent ships were injured, and many lives lost at Colon, through an explosion of nitro-glycerine.* Not long after that a fearful accident occurred in San Francisco at Wells, Fargo & Co.'s express office. A box was noticed to leak some oily substance, and one of the employés took a hammer to drive in a fresh nail so as to keep the box tighter together, when on hammering the box exploded. Later on, a Newcastle magistrate and several other persons fell victims to an accident with this explosive body. In 1868 a factory at Stockholm where nitro-glycerine is manufactured was blown up and a number of men killed, and not long after that an explosion attended with fearful loss of life occurred in Belgium. This last-named accident led to the authorities altogether prohibiting the use of this explosive compound in that kingdom.

The exact cause of these explosions was never ascertained, but general opinion ascribed them to violent concussion of the liquid nitro-glycerine, or to its spontaneous decomposition. Mr. Nobel thinks that the manufacturers were not aware at the time of the immense influence which the metallic packing then used (in the form of tin canisters) exercises, even when inclosed in wooden boxes, on the liability of nitro-glycerine to explode by concussion and vibration of the metal packing.

It was then proposed, and adopted as a temporary measure, to render nitro-glycerine inexplosive, or rather much less sensitive, by adding methylic alcohol, which it readily dissolves. On shaking it with water, which takes up the alcohol, the explosive properties are fully restored, and the same detonator cap, which has not the slightest effect on the mixture of nitro-glycerine and wood naphtha, explodes it after a moment's washing with water. Since the invention of nitro-gelatine, nitro-glycerine has ceased to be used in the liquid state, as the former is just as strong.

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* I arrived in Colon in May, 1866, on my way to California, and saw in the harbour the wrecks of several mail steamers which had been *destroyed* by this explosion.

Gelatinised Nitro-Glycerine.—Nobel has patented a process for solidifying nitro-glycerine by means of gun-cotton collodion. The explosive compound becomes more and more gelatinous in proportion to the quantity of nitrated cellulose which is dissolved therein; and it forms (when 7 to 8 per cent. of the nitrated cellulose has been incorporated) a solid jelly—known as *Nitro-gelatine*—which the inventor claims to be very safe and highly suitable for every purpose to which very powerful explosives can be applied. The details given in the patentee's specification are here set out.*

In some explosive liquids (such as nitrate of methyl) collodion-cotton readily dissolves at the ordinary temperature, and forms a thick explosive gum or jelly. In the case of nitro-glycerine, however, the incorporation of the above-named gelatinising substance is facilitated by adding a small quantity of a substance which promotes the solubility upon which the gelatinisation depends. Such substances are the acetic ethers of glycerine, ethyl, methyl, acetic acid, a mixture of alcohol and ether, acetone, nitro-benzol, dinitro-benzol, the nitrates of methyl, ethyl, and other analogous substances. The quantity of the solvent which has to be added depends upon the nature of the substance chosen; but, as a rule, about 10 per cent. of the weight of nitro-glycerine which has to be gelatinised will be found in practice to be amply sufficient. Moreover, by gently heating nitro-glycerine (in a water bath or otherwise), it acquires the property of dissolving nitrated collodion cellulose without the addition of the promoting solvent; or when it is found advantageous to use the promoting solvent, the application of heat will enable the quantity used to be reduced to 2 per cent., or even less, of the weight of the nitro-glycerine. Since nitrated cellulose is rarely, if at all, of a homogeneous composition, and therefore its solubility in nitro-glycerine will be found to vary, the necessity for adding a promoting solvent must be ascertained by experiment.

The above-described process of gelatinisation necessitates:—

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* The patent is dated 13th October, 1876.

1. That the explosive liquid shall contain no impurity or foreign matter capable of counteracting its power of dissolving nitrated cellulose, or other substance possessing the same property, as hereinbefore described.

2. That only such nitrated cellulose or other analogous substance is to be used which readily dissolves in and gelatinises the explosive liquid.

3. That the solution of the nitrated cellulose or other analogous substance (especially if that substance is twisted or compressed) shall be facilitated by mechanical stirring or kneading so as to allow of the necessary access to all the parts of the nitrated cotton intended to be dissolved.

The explosive jelly which is obtained by this process can be easily pressed into cartridges, or any other forms found convenient for use. For certain purposes, and especially for military use, it is important to be able to dilute or modify the explosive sensitiveness of gelatinised nitro-glycerine in a measure exactly suited to the purpose in view. This is done by adding more or less of a non-explosive or sluggishly explosive substance, possessed of the property of dissolving both nitro-glycerine and the substance which serves to gelatinise it. Such are the acetic ethers of glycerine, methyl, ethyl, and acetone, acetic acid, nitro-benzol, dinitro-benzol, the nitrates of methyl and ethyl, or other solvents of an analogous character. An addition of the above-named, or of any analogous substance, serves not only the purpose of rendering the gelatinised nitro-glycerine less sensitive to concussion, but also reduces its quickness of explosion; it facilitates, as above described, the process of gelatinisation; and it lowers the temperature at which nitro-glycerine becomes hardened or congealed. The least volatile substances, such as the acetic ethers of glycerine, nitro-benzol, dinitro-benzol, deserve preference, inasmuch as they cannot become inactive through evaporation.

Gelatinised nitro-glycerine, when properly confined, can be exploded by a common fuse; but, as a rule, detonators, containing a strong charge of fulminate, are used, as also for firing dynamite. When hardened in cold weather, gelatinised nitro-glycerine explodes more readily than frozen dynamite; still it is a good precaution always to head the charge with a primer, consisting of a small cartridge of gunpowder or gun-cotton, or dynamite, or uncongealed gelatinised nitro-glycerine, or an analogous substance.

Experiments have demonstrated its insensibility to shock, to friction, and to the pressure or action of water; and, further, that to produce complete explosion in a free state, and to develop the great force corresponding to its chemical composition, it would be necessary to use, even in its soft state, a peculiarly powerful detonator.

One gram of fulminate of mercury is insufficient to detonate a charge in a soft state contained loosely in a tin case. Fragments of gelatine as large as a pin's head, or even as a small pea, were found scattered about after an explosion.

Under the blow of a pile engine, the gelatine was insensible to a blow of 3·5 kilogrammetres; while dynamite instantly explodes under one kilogrammetre.

The gelatine is unaffected by submersion in water, even at a temperature of 158° F., and showed no exudation after eight days, at a temperature of 113° F.

Camphor is generally added to render nitro-gelatine insensible to blows, even of projectiles at short range. Nitro-gelatine thus treated is the *Gelatine Explosive de Guerre*, which is largely employed by various Governments for military engineering purposes. A specially prepared primer is required for its complete detonation.

In appearance it is gelatinous, elastic, transparent, and pale yellow in colour. Its density is 1·6; it can be cut with a knife; and under the severest pressure it shows no trace of nitro-glycerine. At a temperature of 122° F. to 140° F., it softens a little, but seldom becomes greasy. When inflamed in the open air, it burns like dynamite, or dry compressed gun-cotton.

Camphorised nitro-gelatine evaporates very little even at a temperature of 158° F., and if it is exposed to that degree of heat for one week.

Pure explosive gelatine, slowly heated, detonates at 400° F., or rapidly at 460° F. Mixed with from 4 to 10° of camphor, this substance will not explode at the same temperature as gunpowder—viz., 570 to 600° F.—but simply burns, producing sparks.

The more camphor nitro-gelatine contains, the more difficult it is to explode, and with a certain admixture of camphor the compound may even be fired into with rifle bullets without detonation resulting.

CHAPTER V.

VARIETIES OF DYNAMITE.

Invention of Dynamite—Kieselguhr Dynamite—Influence of Kieselguhr on Explosive Efficiency—Colonia and Hercules Dynamite—Vulcan—Seranine and Horsley's Powder—Dualine—Lithofracteur—Ammonia Powder—Giant Powder No. 2—Sebastin—Brain's Powder—Rhenish Dynamite—Forcite—Atlas Powder—Gelatine Dynamite—Glukodine—American Hercules Powder—Judson Powder—Paleine or Straw Dynamite—Trautzl's Dynamite—Carbo-Dynamite—Smolianinoff Explosive—Snyder Explosive—Von Dahmen's Safety Dynamite—Classification of Dynamites—American and Belgian Forcite Powder Works.

Dynamite consists of nitro-glycerine absorbed in a porous substance, particularly the silicious infusorial earth, occurring in Hanover, called "kieselguhr." It is erroneously believed to have been discovered accidentally through a leakage of nitro-glycerine into kieselguhr. But the first dynamite made contained no silica; it consisted of porous charcoal and nitro-glycerine; and numerous experiments were made with various absorbents, such as porous terra-cotta, sawdust, ordinary paper, and nitrated paper soaked in the liquid explosive and rolled into cartridges, before porous silica was finally adopted. Kieselguhr absorbs from three or four times its own weight of nitro-glycerine, and possesses the advantage over other absorbents of resisting a greater degree of pressure without parting with any of the nitro-glycerine which it holds. At first the new blasting agent made but slow progress, owing in a great measure to the strong prejudice existing against its chief ingredient. But gradually it has grown into favour and is now universally adopted as a blasting agent.

Dynamite (*Kieselguhr Dynamite*).—The infusorial earth, to be employed as an absorbent, must be freed from organic admixtures, water, and coarse silicious grains. The first two are eliminated by calcination, which is carried out in furnaces situated one above another, usually four of them; the kieselguhr is pushed from the uppermost to the lowest. The calcined mass is then crushed between cylinders and passed through wire sieves.

The saturation of the infusorial earth with the nitro-glycerine takes place in the same building in which the liquid is finally washed. According to *F. Capitaine*, 50 lbs. of kieselguhr are put with treble the weight of nitro-glycerine into flat wooden trays and mixed by hand; the workmen ought to have gutta-percha gloves, but they mostly neglect this precaution. In about half an hour the mixture is completed; the mass is now pressed by hand through sieves, and is ready for being filled in cartridges. The cartridges are of cardboard paper or of vegetable parchment; their mode of filling is very simple and is usually done by hand.

The impression has prevailed until lately, that a chemically inactive absorbent like kieselguhr in dynamite could not exert any influence on the explosive efficiency of a nitro-glycerine mixture; but *Capt. P. Hess* and *Lieut. John Schwab*, while making some comparative experiments with a pressure gauge on two kinds of kieselguhr dynamite, noticed some remarkable differences in their action, which led to the investigation of these substances.

Two samples of dynamite were experimented with, supplied from Nobel & Co.'s factories, one of which came from the factory at Zamky, made in 1872, and the other from the factory at Pressburg, made in 1876.

These samples were compacted into small cartridges, each containing 17 grams, and they were placed on the top of two
ad cylinders, each 20 mm. high and 31 mm. in diameter, the
er one of which was placed on a cast-iron plate. The cart-
did not rest directly on the upper lead cylinder, but a

thin steel disc, 3·5 mm. in thickness, was interposed between the cartridge and the cylinder.

The effect of the explosion made itself manifest by the compression of the two lead cylinders, which, measuring 40 mm. before the explosion, were reduced by the explosion to the following heights:—

1°. Six shots with dynamite of 1872—

27·8 mm.	Height of the compressed cylinders. Average 27·67 mm.
28·2 „	
27·6 „	
27·2 „	
27·4 „	
27·8 „	

2°. Six shots with dynamite of 1876—

26·5 mm.	Height of the compressed cylinders. Average 26·33 mm.
26·6 „	
26·3 „	
26·1 „	
26·8 „	
25·7 „	

The 1876 dynamite showed a greater intensity than the 1872 sample. The chemical examination of the two dynamites gave—

DYNAMITE OF 1872.

Nitro-glycerine	70·8 per cent.
Kieselguhr	28·2 „ „
Water	1·0 „ „

Three determinations of the nitrogen in the nitro-glycerine by Dumas' method denoted the following percentages—

I.	II.	III.	Average.
16·13	16·12	16·12	16·12

DYNAMITE OF 1876.

Nitro-glycerine	70·08
Kieselguhr	28·82
Water	1·10

Nitrogen found in the nitro-glycerine by Dumas' method—

I.	II.	III.	Average.
15·72	15·65	15·68	15·68

According to the preceding analysis, the composition of the two dynamites does not vary sufficiently to account for the difference of intensity-effect which the pressure gauge showed. Still, as there was quite a difference in the effect of the two samples, and as this was in favour of the dynamite of 1876, as this also contained not only less nitrogen in its nitro-glycerine, but also less nitro-glycerine in the mixture than the sample of 1872, the cause for this variation in the effect must be looked for in the structure of the kieselguhr, which in reality shows a great many variations.

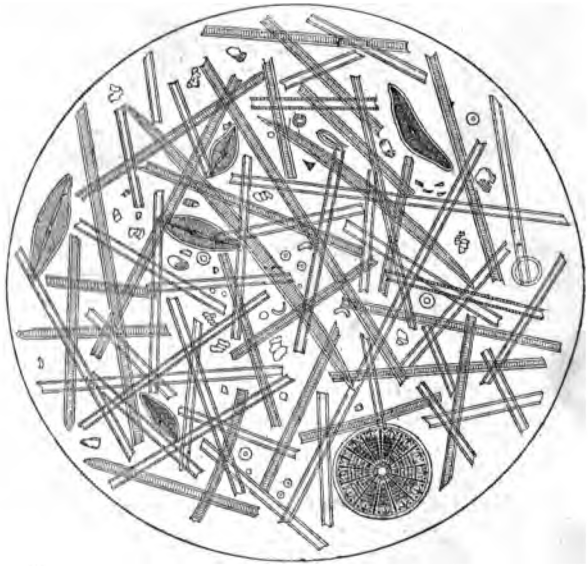

FIG. 6.—KIESELGUHR DYNAMITE UNDER THE MICROSCOPE: SAMPLE OF 1876.

The figures 6 and 7 exhibit the appearance of the two kieselguhrs when magnified to 300 times their natural size, used in these dynamites and extracted from them.

The kieselguhr of the 1876 dynamite shows the long tubular *well-preserved* bacillariæ, whereas the kieselguhr of the 1872 dynamite shows only fragments of the tubular diatomaceæ, but in larger proportion the pleurosigmata and dictyocheæ, which are round, and also numerous granules of quartz.

It is well known that the long tubular bacillariæ absorb the nitro-glycerine much better than the short fragments of the other two kinds. In the dynamite of 1876 every drop of nitro-glycerine was, as it were, packed away in a little vessel and was well absorbed, and the explosion met thereby with a primary resistance in the absorbent, which acted as a kind of tamping in itself, which increased the intensity of the dynamite. In the dynamite of 1872, which appeared and felt fatty to the touch, a portion of the nitro-glycerine was not absorbed, and did not get the tamping effect from its absorbent, and hence it showed less intensity. Therefore, not only through considerations of safety should fatty nitro-glycerine mixtures be avoided,

FIG. 7.—KIESELGUHR DYNAMITE UNDER THE MICROSCOPE: SAMPLE OF 1872.

but also because their intensity-effect is lessened by this condition.

The great success of kieselguhr dynamite has given rise to numerous other nitro-glycerine compounds, of the best known of which I proceed to give a more or less brief account.

Colonia and **Hercules** dynamite are mealed gunpowder mixed with about 35 per cent. of nitro-glycerine, and resemble the first nitro-glycerine preparation brought out in 1863. They are manufactured at Cologne by Wasserfuhr.

Vulcan is also a dynamite, composed of mealed gunpowder holding 43 per cent. of nitro-glycerine.

Seranine and **Horsley's Powder** are chlorate of potash preparations mixed with nitro-glycerine. The substitution of a chlorate for a nitrate is said not to add to the power, while it adds to the expense of the compound, and also somewhat increases its danger.

Dualine was brought out by Ditmar in Germany. It consists of sawdust, nitrate of potash, and nitro-glycerine.

Lithofracteur.—Its ingredients are, nitro-glycerine, 55 per cent.; kieselguhr, 21 per cent.; charcoal, 6 per cent.; barium nitrate and bicarbonate of soda, or either of them, 15 per cent., sulphur and manganese oxide, or either of them, 3 per cent. Manufactured by Krebs, in Deutz.

Ammonia Powder, invented by Ohlson and Norrbin, though comparatively unknown, is far stronger than lithofracteur, and surpasses even dynamite in point of power. Its only drawback is the hygroscopic nature of its chief ingredient, which is ammonium nitrate. But in every other respect it is a very superior blasting agent when freshly prepared, but it has no keeping qualities. It consists of eighty parts by weight of nitrate of ammonium, six parts of charcoal, and fourteen to twenty of nitro-glycerine.

Giant Powder No. 2 (*Dynamite No.* 2) consists of 40 per cent. of nitro-glycerine added to a mixture of forty parts nitrate of soda or potash, six parts resin, six parts sulphur, and eight parts infusorial earth. Other nitrates may be substituted for those above named, and other carbonaceous substances for the resin.

Sebastin, patented by G. Fahnejelm of Stockholm, contains a specially prepared charcoal as the absorbing material. The carbonisation or coking (according to the patentee) must be so done as to completely destroy the organic substances, and to produce as porous a charcoal as possible.

For this purpose young trees or saplings, or branches of poplar, hazelwood, or elder-tree, are selected and burned in an open fire. When the wood has been consumed the fire is not put out by means of water, but left to go out of itself. In this way a very inflammable and very porous charcoal is obtained, which can absorb more than five and nearly six times its weight of nitro-glycerine. The charcoal is pulverised in a wooden mortar, but should not be reduced to too fine a powder, else it will not so completely absorb the nitro-glycerine.

The charcoal produced in the ordinary way is quite different as regards absorbing power. Charcoal of fir-tree may, however, be used, if charred a second time in a special oven.

By mixing different kinds of charcoal a material may be obtained possessing the required absorbing qualities, and an explosive compound may then be obtained of the required power without loss of the necessary consistency; that is, without being too dry, which is undesirable. The charcoal not only serves as a good absorbent for the nitro-glycerine, but it plays also an important part in the combustion. The nitro-glycerine in exploding decomposes into steam, carbonic acid, nitrogen and oxygen.

In the explosion of dynamite with inert base, the oxygen goes away without being utilised; but in the explosion of this new compound a part of the absorbent charcoal is burned by means of the liberated oxygen; the quantity of gas is thus augmented, and also the development of heat, whereby again the tension of the gas is augmented. As, however, the quantity of charcoal necessary for the complete absorption of the nitro-glycerine is in all cases much larger than that which can reduce the excess of oxygen produced at the explosion, nitrate of potash is added.

Brain's Powder contains chlorate, in the place of nitrate of potash; and, as an absorbent, coal dust, sugar, starch, or any carbonaceous material.

Rhenish Dynamite.—This product of the Rhenish Dynamite Company is composed of seventy parts of a solution of 2 to 3 per cent. of naphthaline in nitro-glycerine, three parts of chalk, seven parts of heavy spar, and twenty parts of purified infusorial earth.

Forcite was the invention of Captain J. M. Lewin, of the Swedish service, and is a mixture of nitro-glycerine with cellulose, the latter being gelatinised by heating in water under considerable pressure; but nitrated cellulose is also used in admixture with oxidising salts. As manufactured on a very large scale in America and in Belgium, forcite consists of a thin blasting gelatine, nitro-cotton, incorporated with a mixture of nitrate of soda coated with molten sulphur and wood tar. To this 1 per cent. of wood pulp is added to counteract the sticky qualities of the tar, while the latter prevents the thin blasting gelatine from soaking into the base, which is thus used as a carrier rather than as an absorbent. The explosive meets with remarkable success in America, where the factory on Lake Hopatkong in New Jersey, two hours from New York City (erected under the supervision of the author in 1884), has a capability of turning out six tons of forcite daily; three grades are manufactured there.* Forcite manufactured in Belgium is

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* A description of these works, and also a plan of the Belgian forcite works at Baelen-sur-Nethe, will be found at the close of this chapter.

also meeting with success, and is being used largely in many European and South American countries.*

The subjoined Report† of *General H. L. Abbot*, Lieutenant-Colonel of Engineers, U.S. Army, concerning the forcite compounds, will be read with interest :—

"Forcite presents the appearance of a plastic mass having power of nitro-glycerine, and being attended in its making, carrying, and keeping with less danger than explosive compounds before known, and even than 'blasting' or 'mining 'powder' properly called.

"It has the remarkable and most advantageous property of exploding when confined or charged in a drill hole, as well by the action of special primers or caps, and if specially prepared for the purpose, with a fuze alone, and of burning without explosion in the open air. Its manufacture is less costly than other compositions of nitro-glycerine. The nitro-glycerine is so perfectly united with the other materials that it is not separated by sulphuric ether or alcohol, and that water has no action upon it. The nitro-glycerine therefore preserves its properties without alteration, even under water." [I have kept forcite under water for 24 hours without its losing any of its explosive properties.—M. E.]

"The base for all grades of forcite is, as described in the nitro-glycerine patent, mixed with a special kind of cellulose, which permits the operation and manufacture to be carried on cold, ensuring entire safety in handling and storage, the properties of the nitro-glycerine being unchanged by the avoidance of the intense heat heretofore necessary, as in the case of Nobel's formula, which requires a high temperature for the gelatinising process. This is overcome in the forcite formula, which produces a plastic waterproof compound ranging from

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* Since these pages were put in type, forcite (after examination by H.M.'s Inspectors of Explosives) has been put upon the list of "authorised explosives" under the Explosives Act, 1875 (see *post*, pp. 276–7).

† Published in his 'Report upon Investigations to develop a System of Submarine Mines for defending the Harbours of the United States,' constituting 'PROFESSIONAL PAPERS, NO. 23, CORPS OF ENGINEERS, 1884.'

80 to 30 per cent. of nitro-glycerine; and by the addition of saltpetre, as an absorbent, the quantity of nitro-glycerine can be reduced, while preserving a high standard of explosive strength. The use of a hydro-carbon as a solvent of the forcite mixture renders forcite waterproof as a result. It will be perceived that forcite, in many respects, resembles Nobel's explosive gelatine, which is not as yet manufactured in the United States. Possessing special interest as the only American representative of this latest order of modern high explosives, it has been carefully tested at Fort Willet's Point during the past season.

"The following grades were selected for trial:—

Forcite gelatine,	containing	95%	nitro-glycerine	and	5%	cellulose.		
Forcite No. 1	,,	75%	,,	,,	25%	explosive base.		
Forcite No. 3	,,	40%	,,	,,	60%	,,	,,	
Forcite No. 3 A.	,,	30%	,,	,,	70%	,,	,,	

"The varieties used in my trials all had the yellow tint characteristic of explosive gelatine, but less bright—the base being apparently sodium nitrate with a trace of rosin, from a rough test made after partial deliquescence.

"The strongest sample (95 per cent. of nitro-glycerine) looked quite like the explosive gelatine made in this country, and tested by me in 1881. It was more mottled and slightly darker than the Scotch gelatine, which has a beautiful semi-transparent yellow tint. Exposed for several hours to a temperature of 100° F., a slight exudation of nitro-glycerine was detected in the forcite gelatine, but none in Nobel's; but it must be remarked that the latter only contained 93 per cent. of nitro-glycerine, not 95 like the forcite gelatine.

"The specific gravity of forcite, by careful measurement, was found to be the following:—

Forcite gelatine	1·51
,, No. 1	1·60
,, No. 3	1·66
,, No. 3 A.	1·69
That of the Scotch explosive gelatine was	1·53

"All the forcites were somewhat elastic to the touch, the lower grades being the harder. The lowest grade exhibited a decided hardness and friability as compared with the highest.

"Fourteen shots were fired with each of these grades of forcite in the four or five foot rings submerged about 35 feet in water about 80 feet deep. The charges were contained in the usual tin cans, and were exploded with the service fuze containing 24 grains of fulminating mercury. Four of the charges with each grade also contained a 3-ounce tonite primer, to indicate whether the fuze alone was sufficient to ensure perfect detonation. The registered pressures were not thereby increased, indicating that no extra primer is required.

"The results of my tests and their analysis justifies the claim of the Forcite Powder Company, that the higher grades of their explosives are far more powerful than any others in our market, at least when fired under water in the manner of these trials. The permanency of its composition when in store for long periods remains to be tested by time. Cartridges of the three lower grades, stored for a few weeks in a damp magazine, showed an incipient deliquescence of the sodium nitrate." [This could be obviated by using the potassium nitrate.—M. E.]

"The following trials were made to determine the degree of sensitiveness of forcite to the rough treatment it might receive if carried in the engineer trains of an army in the field :—

"Half a pound of forcite gelatine was lashed to a board and fired at with a Springfield rifle at twenty yards' range. The first shot grazed the cartridge without effect; but the second caused a loud explosion, shattering the board. The same test was applied to No. 1 with a like result. Hence forcite cannot be regarded as safe when exposed to musketry fire. A small quantity ignited by a match blazes with a hot flame, but does not explode. No trials were made with large amounts, but the usual dangerous result may be anticipated." [An addition of camphor ought to obviate this defect.—M. E.]

"The following trials were made to determine the sensitiveness of forcite to shocks of neighbouring mines transmitted through the water, a very important matter in submarine mining :—

"The primary charges each consisted of one pound of dynamite, No. 1, submerged 5 feet in water 16 feet deep. The secondary charges each consisted of half or three-quarters of a pound of forcite wrapped in thin rubber cloth. The following results were obtained :—

"*Forcite-Gelatine.*—The secondary charges failed at 10 feet, 8 feet, 7 feet, and 6½ feet. At 6 feet one charge failed and three charges probably exploded. At 5 feet one charge certainly exploded.

"*Forcite*, No. 1.—The secondary charges failed at 20 feet, 14 feet, 10 feet, 8 feet, 6 feet, 5 feet, and 4 feet (2 trials). At 3 feet, one charge certainly, and another probably, exploded.

"These experiments prove that the higher grade is the more liable to sympathetic explosion, but that both are far less sensitive than dynamite No. 1, which under like conditions explodes at about 20 feet. In fine, these investigations indicate that forcite, now for sale in our market, must be classed as one of the explosives worthy of serious consideration when it becomes necessary to defend our coast with submarine mines. Its great strength is fully established; its permanency for long periods of time remains to be studied.

"Assuming dynamite No. 1 as the standard, and giving it the value of 100, the different grades, as fired under water, gave in a horizontal plane through the charge the following relative intensity :—

Forcite gelatine	95%	nitro-glycerine =	133	intensity.
,, No. 1	75%	,, ,,	124	,,
,, No. 3	40%	,, ,,	95	,,
,, No. 3 A.	30%	,, ,,	88	,,
Dynamite	75%	,, ,,	100	,,
Explosive gelatine from Glasgow	93%	,, ,,	142	,,
Compressed gun-cotton			87	,,
Pure nitro-glycerine			81	,,

"From the above we see that :—

"1. Pure nitro-glycerine does not give great intensity when under water.

The opinion that the value of a dynamite is proportionate to the percentage of nitro-glycerine the same contains is erroneous, at least for submarine mining.

"3. The addition of an explosive base increases enormously the value of a dynamite."

Atlas Powder is a form of dynamite which has a rather unenviable reputation in England, due to its having been the explosive used in the outrages which were committed in London a few years ago by the so-called dynamiters. It is manufactured at the Repauno Chemical Works, near Philadelphia, and it is a composition of nitro-glycerine, wood fibre, and nitrate of soda, with 2 to 3 per cent. of carbonate of magnesia. Seven grades of it are made, containing from 20 to 75 per cent. of nitro-glycerine. They are lignum dynamites.

Gelatine Dynamite consists of a thin blasting gelatine mixed with other substances, such as nitrate of potash and wood meal. There are two grades manufactured in England, one containing 80 and the other 60 per cent. of nitro-glycerine. The great advantage of the plastic dynamites like gelatine dynamite, and also of forcite, is that they can remain in water without being affected or losing their strength.

Glukodine (as described by Major Cundill*) is a whitish liquid produced by the nitration of a saturated solution of cane sugar in glycerine. Free sugar dissolves in it, and it is soluble in ether. Two sorts of glukodine powder are made, white and black.

Samples of it showed the following composition :—

	White.	Black.
Matter soluble in ether (glukodine)	36·40	34·24
Free sugar	8·40	8·76
Soda salts (mostly nitrate)	31·20	37·84
Nitro-cellulose	23·36	—
,, ,, and charcoal	—	19·31

Another analysis of the same samples showed that the glukodine in the white powder consisted of 33·19 parts of nitro-glycerine to 3·21 parts of nitro-saccharose, and in the

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* In his 'Dictionary of Explosives.'

black powder of 30·23 and 4·03 parts of the same ingredients respectively. Subsequent experiments appeared to show that glukodine was simply a mechanical mixture of those ingredients, as the nitro-glycerine could be readily evaporated off from the nitro-saccharose.

American Hercules Powder.—This is identical with *Nitro-Magnite*, as magnesia alba (or carbonate of magnesia) is used as the absorbent. It is manufactured on a very large scale in America, and I have usually heard the miners speak very favourably of it, claiming that the fumes were not so bad as from other dynamites. The reason of this I ascribe to the presence of the alkaline absorbent, which, in exploding, gives off explosion gases in which no carbonic oxide is present, and possibly the nitrogen also may enter into combinations which do not affect the organism. Its composition is as follows:—

	No. 1.	No. 2.
Carbonate of magnesia	20·85	10·00
Nitrate of potash	2·10	31·00
Chlorate of potash	1·05	3·34
White sugar	1·00	15·66
Nitro-glycerine	75·00	40·00

Judson Powder differs from dynamite, as in the latter the nitro-glycerine is absorbed, whereas the principle of the Judson powder is to render the oxidising salts (nitrates) non-absorbent, by coating them with a varnish of hydrocarbons, which on hardening renders the granules non-absorbent, and also non-hygroscopic. To the "dope" so prepared 10 per cent. of coarsely-ground anthracite is added, and to this mixture 5 per cent. or 6 per cent. of nitro-glycerine is added, forming a coating or film over the granules, which renders the dope explosive. This explosive has met with great success in America, it being very cheap and more powerful than the common mining powder.

Paleine or **Straw Dynamite** is a mixture of nitro-cellulose, made from straw with nitro-glycerine; it is manufactured in Sardinia and Belgium.

Trautzl's Dynamite is a mixture of nitro-glycerine and gun-cotton pulp, consisting of

Nitro-glycerine	75 parts
Gun-cotton	25 ,,
Charcoal	2 ,,

Carbo-dynamite.—Carbo-dynamite is a recent British invention which owes its origin to Messrs. W. D. Borland and W. F. Reid. The base is nitro-glycerine, and the absorbent is carbon. It is as cheap as ordinary dynamite, and is alleged to possess several advantages over it. For example, it has much greater explosive force, seeing that 90 per cent. of the compound is pure nitro-glycerine, and that the absorbent itself is highly combustible. In addition, it is claimed that, when the dynamite is wet, no exudation of nitro-glycerine takes place from the absorbent. It is even declared that some carbo-dynamite which had lain for eight months in water presented at the end of that period the same appearance as when first immersed, and had suffered no deterioration of its explosive qualities.

Smolianinoff Explosive.—The Smolianinoff explosive, which also has been experimented with (in America) of late, consists of 80 per cent. of nitro-glycerine combined with a certain fluid, the nature of which is a secret.

It was used as a bursting charge for shells, and seems to withstand the shock produced by heavy gunpowder charges when fired from guns. A 100-pounder Parrott gun was employed, and three shells were fired, the first two weighing 89 lb., and carrying 4·6 lb. of Smolianinoff explosive, and the third weighing 82 lb., and having a 4·1 lb. bursting charge. The firing charge in each case was 18 lb. of Dupont powder, the range was 101 yards, and the muzzle velocity was about 1490 feet. The first shell was not fused. It struck the target and broke up with a low explosion, doing only superficial damage. The second shell was fitted with a detonating percussion fuze. It struck the target, exploded with much more force than had been developed by the unfused shell, did some surface damage, and badly injured the target's foundations. The third shell produced much the same results. No damage was done to the gun, and the weakness of the cast-iron shells which were used, as well as the shape of the heads, which were suitable only for a nose fuze, were held to be mainly responsible for the unsatisfactory nature of the experiments. These, we hear from other sources, are to be repeated under more favourable conditions.

Snyder Explosive.—The Snyder explosive has recently been tested in Turkey as a bursting charge for shells, with very successful results. It consists of 94 per cent. of nitro-glycerine and 6 per cent. of a compound of collodion, gun-cotton, camphor, and ether; and it is exploded by mere percussion against any hard body. It is, nevertheless, said to be safe to handle. The gun employed was a 6-inch rifled piece. The target, 220 yards away, was composed of twelve 1-inch steel plates, welded together and backed with 12-inch and 14-inch oaken beams. It measured 14½ feet by 4½ feet, and weighed more than 20 tons. The charge of Snyder explosive was 10 lb. The target was utterly destroyed at the first shot, and nine other shots were fired without accident of any kind. Experiments have also been made with this explosive in other countries, by firing it from a gun as a bursting charge for shells.

The explosive is the invention of Mr. F. H. A. Snyder, of New York, and appears to have an important future.

Von Dahmen's Safety Dynamite. — According to reports recently published, *Baron von Dahmen*, a German scientist, has discovered the means of preventing nitro-glycerine compounds from being affected by a low temperature, as already at 40° F. a congelation of the oil takes place (see page 24), and of rendering all classes and grades of dynamite non sensitive to the initial explosion of the detonators, thus dispensing with the troublesome and dangerous operation of thawing.

I am not aware what means Baron von Dahmen employs to prevent the congelation of the nitro-glycerine, but if this discovery is a true one it will be of great importance, especially for northern countries, and even those lying within the temperate zone. I see no reason why some substance should not be introduced which, when blended with the nitro-glycerine, would change the character of the latter, rendering it less sensitive to cold, without affecting its other valuable properties.

It is stated that when Von Dahmen's dynamite is left in an ice machine for twenty-four hours, exposed to a freezing temperature, it maintains not only its plasticity but also explodes readily, whereas ordinary dynamite submitted to similar conditions failed to explode, even with triple force detonators. Such an invention, if practically demonstrated, will certainly meet with great favour among all classes of miners and blasters, who are fully aware of the great chapter of accidents resulting from the thawing operation, and the many "miss shots" from frozen dynamite.

Classification of Dynamites.—From the above enumeration of the many compounds which have been brought before the public, it will have been seen that in nearly all of them the nitro-glycerine is mixed with or absorbed by an active base, or "dope," as the Americans style it; and for this reason the dynamites may be divided into two groups:—

1. Dynamites with an inert base, such as kieselguhr, which acts merely as an absorbent for the liquid nitro-glycerine. This was Nobel's original invention.

2. Dynamites with an active—*i.e.*, a combustible or explosive—base.

The idea of substituting an active base which in itself is a combustible—or, in the sense of the Explosives Act, an "explosive" proper—in lieu of the inert kieselguhr, is an excellent one: the strength of the explosive itself is increased by rendering the absorbent matter explosive, and a more perfect combustion is insured when the charge is fired.

Major Cundill, besides adopting the classification just indicated, has made a subdivision of group 2 into three minor classes—viz., those which contain as a base.

a. Charcoal.
b. Gunpowder, or other nitrate or chlorate mixtures.
c. Gun-cotton, or other nitro-compounds.

He also gives* the following rough-and-ready tests for ascertaining whether a given substance contains nitro-glycerine :—

"If a liquid is oozing out or can be squeezed out from the substance, put the drop on to blotting-paper. If this is nitro-glycerine it will make a greasy stain, not disappearing or drying away; struck with a hammer on iron a loud report will be heard; lit and burnt, it will give a crackling sound and a greenish flame. If gradually heated by a flame underneath, it will give a sharp report.

"Again, put a portion of the substance into a test tube and shake it up with methylic alcohol (wood spirit), first ascertaining that the spirit poured into water causes no turbidity or milky appearance. Filter the contents of the tube into another tube, and add pure water to the latter. If nitro-glycerine is present, a milky appearance will be produced, and the heavy liquid will eventually settle at the bottom of the tube.

"A much more delicate test is to use aniline and concentrated suphuric acid as re-agents. In the presence of nitro-glycerine a purple colour is produced, which changes to green on the addition of water.

"Nitro-glycerine explosives, unless carefully made from pure ingredients, are apt to decompose spontaneously. Any indication of acid fumes, or any tinge of green in them, should be followed by their prompt destruction, with suitable precautions."

Forcite Powder Works.—The following description of these works (which are previously referred to in this chapter) appeared in the *Mining Herald and Colliery Engineer* of Philadelphia (March 1884) :—

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* 'Dictionary of Explosives,' p. 39.

"The works of the American Forcite Powder Manufacturing Company, at Lake Hopatkong, Morris county, New Jersey, are completed, and the manufacture of explosives has commenced. The works are the most extensive in the country, numbering upwards of forty buildings, covering an area of several acres, heavily wooded. The narrow gauge railroad which connects them is nearly a mile in length. The buildings where the powder manufacturing is to be done are situated from 100 to 200 feet apart, and placed in excavations in the side hills, so that only one side is exposed. All these buildings are lined, ceiled, heated by steam, and furnished with water. The building containing the machinery is 84 × 44 feet, and is divided into four fire-proof compartments. Embraced in the very excellent machinery plant is an Ingersoll duplex air compressor. The glycerine converting house is a three-story frame building 32 × 32 feet. The converter is in the third story, the separating tanks and washing tanks are on the lower floors. The spent acid flows through leaden pipes to the acid house, where it is regenerated and forced back to the converting house, 900 feet away, by means of compressed air. The acid regaining factory is a brick building 25 × 05 feet, and contains four large retorts and condensing towers for regenerating the spent acids.

"The nitro-glycerine is carried from the converting house to the mixing houses, by gravity, through large indiarubber pipes, well protected and laid under ground. After passing the two mixing houses, through a cut in the hill are reached three buildings where the forcite is modelled into cartridges by machines which are run by compressed air, and the power is transmitted to the other buildings with wire ropes; then come two packing houses where the cartridges are boxed, and then two magazines which are built in excavations in the hill, so that the roofs are below the surface of the ground. The structures are of brick with roofs of corrugated iron. This roof forms a lightning conductor, and has rods leading from the four corners into the ground, as in the Belgian Government magazines. A system of ventilation, through hollow bricks, allows the air to enter at the bottom and escape at the top.

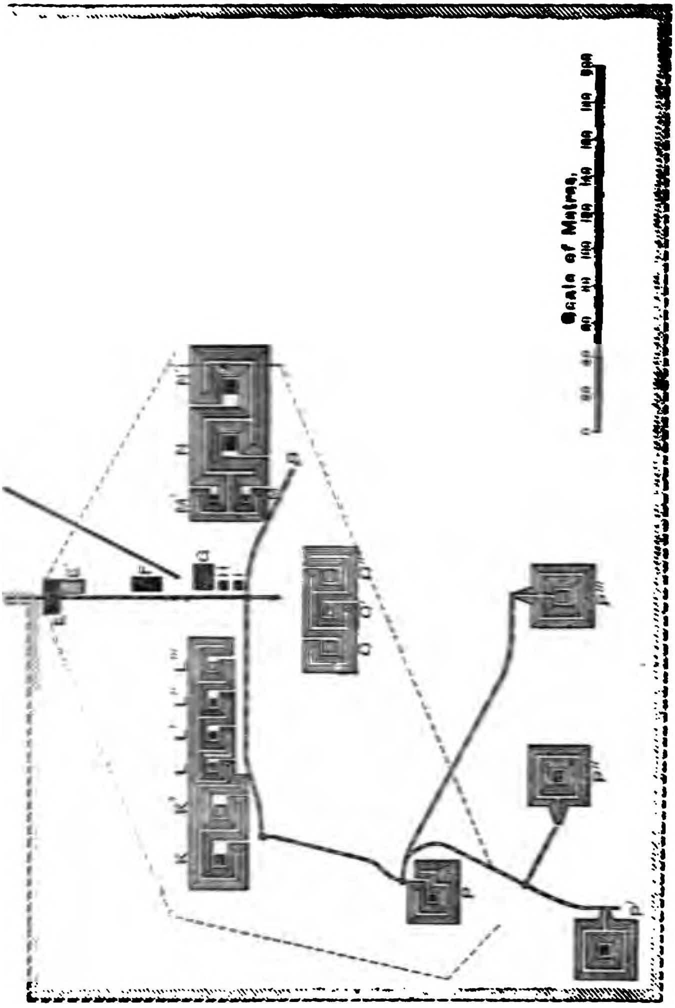

FIG. 2. PLAN OF FORCITE WORKS AT BAELEN-SUR-NETHE, BELGIUM.

A reservoir, capable of furnishing 60,000 gallons of water daily, is connected with the works, fed from an artesian well giving water at 8° Celsius. The concern has a capacity of six tons of powder per day, and, beginning with a force of 50 men, it is expected soon to increase the same to 100.

"These works have been erected under the personal supervision of Mr. M. Eissler, the manager, who has had a large experience in the manufacture of powder in California, and who has combined the experience and practice of the largest powder manufacturers of the world in the new works."

Belgian Forcite Works.—The annexed plate (Fig. 8) shows the plan of the Belgian forcite works at Baelen-sur-Nethe. All dangerous buildings are surrounded by strong parapets, forming a perfect protection in case of accident, and to localise any explosion which may occur in any one building. It is a model factory, provided with all modern appliances for making safely and easily two tons of forcite per day. In the plan—

E, E′, are storehouses for the raw material.
F, carpenter's shop and laboratory.
G, machine house.
H, regenerating apparatus for the spent acids.
I, chimney.
K, K′, packing houses.
L, L′, L″, L‴, cartridge houses.
M, M, nitro-glycerine washing apparatus.
N, N′, ,, ,, factories.
O, O′, O′, mixing houses.
P, P′, P″, P‴, powder magazines.

CHAPTER VI.

APPLICATIONS OF GUN-COTTON.

Earlier Experiments—Results of Sir F. Abel's Researches—Manufacture of Gun-cotton rendered Harmless—Diluted and Undiluted Gun-cotton—Wet Gun-cotton for Military Purposes—Compressed Gun-cotton or Submarine Mining—Transmission of Detonation in Water—Transmission of Detonation through Air.

Since the introduction and speedy abandonment in Austria, about twenty-three years ago, of gun-cotton arranged in the form of compactly wound thread (Von Lenk's system), as an explosive agent for field guns, attempts to use it as a substitute for gunpowder for artillery have been limited to experiments conducted at Woolwich in 1867 and 1868 with cannon cartridges of compressed gun-cotton. Considerable progress was made at that time towards the production of a thoroughly safe cartridge for field guns, but the experiments were suspended when much evidently remained to be accomplished before the requisite uniformity of action could have been secured. The difficulties since encountered in moderating and regulating the explosive force of gunpowder, when employed in very large charges, have shown how remote is the prospect of successfully applying explosive agents of greater violence to artillery, excepting in the smallest calibres. Success has on many occasions attended the employment, in small arms, of explosive agents differing considerably in character from each other, but all of them more rapidly explosive, and therefore more violent, than gunpowder. The chief advantages claimed, and more or less established, for some of them over gunpowder were the production of comparatively little or no smoke, the reduction of fouling, and increased projectile power, with the employment of comparatively small charges.*

The first attempts to apply gun-cotton in small arms, soon after its discovery in 1846, were disastrous in their results; and the success which, long afterwards, was believed to have been achieved by Von Lenk's indefatigable labours in this direction, was not confirmed by experience. Several methods of reducing the rapidity and increasing the uniformity of action of gun-cotton in small arms have since been experimented with in England. Some of these, which consisted in the uniform dilution of gun-cotton, either with ordinary cotton or with the less explosive varieties of the material, have furnished tolerably efficient cartridges for sporting purposes; but the only direction in which substantial prospect of success has hitherto attended the employment of gun-cotton in arms of precision has been that of converting the very finely divided substance into pellets or grains, of which the rapidity of explosion has been retarded by their uniform impregnation with small quantities of some perfectly inert material, each small particle of gun-cotton being enveloped and separated from those surrounding it by a film of non-explosive substance (*e.g.* paraffin, stearine, or caoutchouc).

Von Lenk's persevering efforts to improve the manufacture and devise methods of application of gun-cotton, though in themselves not crowned with any permanent success, have contributed considerably to secure an unassailable position for that material as a valuable and safe explosive agent, by leading to its systematic study in England, and the consequent development of its manufacture, and the discovery of its most valuable properties.

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* I have been informed lately on good authority that the French Government are using a powder in their Lebel rifle, which proved, at a trial where five cadavres (corpses) were placed at certain distances one behind the other, that the bullets passed through the five bodies when fired at from a distance of 400 metres. Such results, no doubt, will ultimately lead to the abandonment of gunpowder in small arms.

Result of Sir F. Abel's Researches.—It is especially through the persevering efforts, and the results of analytical and synthetical researches of *Sir Frederick Abel*, that gun-cotton has taken rank as the modern explosive *par excellence* for war purposes, and also for special mining work.

Pure gun-cotton has the formula $C_6 \left. \frac{H_7}{3\,NO_2} \right\} O_5$. Sir Frederick Abel found that the instability of gun-cotton, as manufactured by Von Lenk's process, arose from imperfect purification, and the presence of minute quantities of foreign substances (susceptible of removal by searching purification) of comparatively unstable character, produced by the action of nitric acid upon resinous and fatty substances retained by the cotton fibre.

The practical trials made, for the English Government, of gun-cotton in the different forms proposed by Von Lenk for employment in artillery, shells, small arms, and mines, and Abel's investigations on the influence of the mechanical condition of gun-cotton upon the rate of its explosion under different circumstances, proved that the control believed to have been obtained by Von Lenk's system of preparation, over the explosive power of gun-cotton, was very limited; and that, while it was indispensable to the development of its full explosive force, that it should be very strongly confined, even the most compact arrangement of the gun-cotton fibres, composing a cartridge to be used in a cannon or small arm, did not impede the almost instantaneous penetration of the heated gases (produced by the first ignition throughout the mass), and could therefore not be at all relied upon to reduce the rapidity of explosion of gun-cotton when ignited in a nearly closed chamber, as in the bore of a gun.

The system of manufacture devised by Sir Frederick Abel, which assimilated gun-cotton in its mechanical condition to gunpowder, the finely divided material being converted by pressure into uniformly compact masses of any convenient form, led, as already pointed out, to a great advance in the safe and efficient application of the substance to small arms, and was also productive of results in the application of gun-cotton for filling of shells.

Its development into a manufacturing process resulted in very important improvements in the directions of economy, facility and rapidity of production, and had the effect of considerably raising the standard of purity of the material.

The cheapest description of cotton (machinery waste) became available as a source of gun-cotton, and the reduction of the fibre to a fine state of division greatly facilitated the application of very searching purifying processes.

Manufacture of Gun-cotton rendered harmless.—The manufacturing operations became absolutely safe throughout, as even the conversion of the finished product into the compressed masses of the various forms in which it receives application is carried out with the material in a wet, and therefore perfectly non-inflammable, state. How harmless the manufacture of gun-cotton is considered, it is sufficient to state that the Stowmarket factory lies within the town limits, and is surrounded by dwelling-houses.

The minute state of division of the gun-cotton also permits of its being readily and intimately mixed with substances of a nature calculated to moderate the rapidity and violence of its explosion, or with the full proportions of oxidising salts required for the attainment of the maximum amount of work from the carbon of the cellulose.

Lastly, the conversion of gun-cotton into homogeneous highly compressed masses has resulted, as will presently be seen, in the establishment of other most valuable and previously unsuspected properties of gun-cotton.

The only, though very serious check which the development of gun-cotton has experienced in England, namely the severe explosion which occurred at the manufactory of Messrs. Prentice, at Stowmarket, in 1871, has been productive of beneficial results; firstly, because a very searching inquiry, instituted by the Government, into the cause of that explosion demonstrated that it was quite unconnected with any defect in the stability of the material when purified according to the present system and, secondly, because the violent explosion of a considerabl store of compressed gun-cotton, which in small quantities onl burns rapidly, even when moderately confined, led to an in tigation of the conditions attending violent explosion co sequent upon the accidental ignition of gun-cotton stores.

Diluted and Undiluted Gun-cotton.—*Sir Frederic Abel* has also investigated the influence of dilution by solids and liquids on the susceptibility of explosive compounds, generally, to detonation, and has demonstrated that, if a finely divided solid explosive body, such as gun-cotton, be diluted with a solid inert substance, soluble in water, and the mixture be compressed into compact masses with the aid of water, it is obtained in a condition of greater rigidity (by the crystallisation of the soluble diluent), and therefore in a form more susceptible to the detonating effect of a small fulminate charge, than when the undiluted explosive by itself is very highly compressed, because the particles of the hard mass oppose greater resistance to the force developed by detonation. The reduction of activeness due to even considerable dilution is consequently almost counterbalanced by the greater rigidity of the mass; and, if in the case of gun-cotton the diluent be a soluble oxidising agent (such as saltpetre), the predisposition to chemical reaction between the two substances operates, in conjunction with the effects of the crystallised salt, in imparting rigidity to the compressed mass, and the latter is consequently quite as sensitive to detonation as though it consisted only of gun-cotton. If this substance is diluted with a liquid, its sensitiveness to detonation is very greatly reduced; thus a considerably increased amount of mercuric fulminate is required to detonate gun-cotton containing 10 to 15 per cent. of water, as will be shown hereafter.

Wet Gun-cotton for Military Purposes.—The readiness and certainty with which wet gun-cotton may be applied to the various operations hitherto carried out with dry gun-cotton, or with nitro-glycerine preparations, have been demonstrated by numerous explosive experiments, and there is no question that for all military purposes a most important advantage in point of safety and simplicity has been gained, as the stores of this explosive agent may not only be kept in an absolutely uninflammable condition, but may be issued in that state for actual use. Thus the requisite material for the rapid destruction of bridges, stockades, or fortifications,* may be carried out with an army in the field without any risk of accident. Experiments which have been carried out by the Austrian artillery and engineer committees, and by the Government committee on gun-cotton in England, have shown that, if ammunition wagons containing packages of dynamite are fired into from military rifles, even from a distance of 1000 paces, explosion invariably results ; dry compressed gun-cotton under the same conditions is frequently inflamed by the penetration of a bullet fired from a much shorter distance, but is never exploded, while wet gun-cotton in a condition ready for service cannot possibly be ignited by the same means, even at the shortest ranges.

Compressed Gun-cotton for Submarine Mining.—The application of compressed gun-cotton to submarine mines has been made the subject of extensive experiment in England ; and the comparative force exerted at various distances and depths of immersion, by large and small quantities of that material, confined in various ways, as well as of dynamite and other explosive agents, has been examined by means of the so-called crusher gauges, which have been applied to the measurement of the pressures exerted by exploding gunpowder. Many results of interest and importance have been obtained, of which it may be mentioned that dry compressed gun-cotton and Nobel's dynamite prove to be on an equality with each other,†

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* See 'Modern High Explosives,' art. "Their application for Military purposes."

† These results are not corroborated by General Abbot's researches, whose measurements of intensity under water are given on page 44.

but that very decidedly greater effects were obtained by employing gun-cotton saturated with water, when closely but not strongly confined round an initiative charge of dry gun-cotton. Another important observation made in these investigations is that, provided the wet gun-cotton closely surrounds the detonator of dry gun-cotton, any small spaces between them and between the individual masses comprising a charge, may be filled with water without in any way interfering with the transmission of detonation throughout, or with the attainment of the maximum of destructive effect. Thus results, fully equal to the highest ever obtained by the explosion of gun-cotton in strong metal cases under water, have been furnished by charges which were simply held together by means of an ordinary fishing-net.

Transmission of Detonation in Water.—In examining into the power of water to transmit the force developed by detonation, *Abel* was led to make experiments of a novel character in hollow projectiles, which have furnished results of considerable interest, and have been shown, by experiments carried on at Okehampton, near Dartmoor, to possess great practical value. If only a small piece from 0·25 to 1 oz. of compressed gun-cotton be exploded, by means of a detonator, in the interior of a shell which is filled up completely with water, and closed, the force developed is so suddenly and uniformly transmitted in all directions that the thick hollow sphere or cylinder is broken up into seven or fourteen times the number of fragments produced by filling the shell completely with gunpowder or a more violent explosive agent (that is, from 30 to 60 times the weight of the gun-cotton used). In this simple way a hollow projectile of ordinary construction may be made to exercise the functions of a shrapnel shell. Detonations less sudden than those obtained with the small cylinder of compressed gun-cotton produced much inferior results, although considerably larger quantities of the explosives vere used. Again, by filling a shell completely with a mixture vater and finely-divided gun-cotton, and detonating in it a charge of 1½ or 2 oz. of dry gun-cotton, the shell being tightly closed, the resistance opposed at the first instant, by the strongly confined mixture of solid and liquid, to the force developed, being similar to that offered by a powerful solid body, the small particles of gun-cotton, though enveloped in and separated from each other by water, are in a position favourable to detonation, and hence a mixture absolutely harmless under all ordinary circumstances becomes a most formidable exploding agent in shells. The difficulty of employing gun-cotton in hollow projectiles, arising out of the liability of their premature explosion by the concussion to which they are subject on firing the guns (and which has been found to apply equally to dynamite), appears thus to have been satisfactorily overcome.

Transmission of Detonation through Air.—This also has been made a subject of investigation by *Sir Frederick Abel*, following up some interesting results on the transmission of detonation through tubes which had been obtained by Trauzl with dynamite, and by Champion and Pellet with iodide of nitrogen.

He has traced to very simple causes some remarkable differences in the apparent power of tubes of different kinds to transmit detonation, and has furnished several demonstrations of the influence of the volume and quality of a detonation upon the results obtained. He has also proved, by small and large experiments, that the *explosion* of a substance may be brought about as a phenomenon distinct from that of its *detonation*, in regard both to the conditions to be fulfilled for its development and the mechanical effects produced by it. Lastly, he has successfully applied a Noble's electric chronoscope to the determination of the velocity with which detonation is transmitted along a continuous mass or a row of distinct masses (either touching each other or spaced) of compressed gun-cotton, of dynamite and nitro-glycerine. Trains or rows of the materials, varying between 24 and 50 feet in length, were employed, and the records of the rate of progress of detonation at different parts of the train were generally remarkably uniform, being mostly quite as high at the termination as at the commencement of the line of explosive material. The velocity with which detonation is transmitted along continuous rows of gun-cotton slabs or cylinders ranged from 17,000 to 20,000 feet per second, varying with the extent of contact between the individual masses employed, and with their density or compactness, but being unaffected by their form or by very considerable variations in their weight. The compressed mixtures of gun-cotton and saltpetre (nitrated gun-cotton) did not, as might have been anticipated, transmit detonation as rapidly as pure gun-cotton; but the velocity of transmission of dynamite was somewhat more rapid, ranging between 19,500 and 21,500 feet per second. It was remarked, however, that while the intervention of spaces of 0·5 inch, and even more, between the individual pieces of a row of compressed gun-cotton masses of a particular weight did not, or only very slightly, affect the rate at which detonation was transmitted, a similar spacing of masses of corresponding weight of dynamite had the effect of reducing the velocity of its detonation to less than one-third that of the velocity observed with a continuous row of cartridges. This result of unconfined nitro-glycerine itself was ascribable to the physical peculiarities of the substances. Compressed gun-cotton saturated with water transmitted detonation with decidedly greater velocity than the air-dried material, a result which is in accordance with the greater sharpness or violence of action observed in practical experiments with the wet material, and is due to its increased rigidity at the moment of its exposure to the force of detonation, consequent upon the replacement of air in the pores by the comparatively incompressible liquid. In iron tubes containing small charges of gun-cotton separated by intervals of 2 and 3 feet, the detonation was transmitted, from the initiative explosion to the first charge, at a rate of about 12,000 feet, but after that it travelled from charge to charge only at an average rate of about 6000 feet per second.

CHAPTER VII.

MANUFACTURE OF GUN-COTTON.

NE of the Process—Gun-cotton distinguished from Collodion-cotton —Gun-cotton an Ether of Nitric Acid—Manufacture of Gun-cotton at Le Bouchet—Manufacture at Waltham Abbey.

E nitric acid used in the manufacture of gun-cotton is 1·45 to 1·50 sp. gr., and must be perfectly pure—that free from chlorine — because an acid containing the substance produces a less effective gun-cotton. It is of great importance that the nitric acid be of the greatest ength.

In the production of gun-cotton large quantities of water formed, and hence if nitric acid *alone* were used it would become so diluted as to be unable to produce gun-cotton, t in its stead the less explosive collodion-cotton. For that son Schönbein and Böttger used a mixture of nitric and phuric acids. Thus the nitric acid remained during the ocess in a tolerably concentrated condition, the water formed ring the reaction being absorbed by the sulphuric acid. glish sulphuric acid of 1·85 sp. gr. is used.

Heating of the acid mixture is to be avoided, because erwise products are formed similar to those formed by the taneous decomposition which sometimes occurs after long ars of storage. The resulting product is not then explosive.

The gun-cotton, when formed, must be most carefully freed washing from the still adhering acids. If not so freed, it ll be liable to spontaneous decomposition or explosion. In mer years this important point was often neglected, and the ult was the explosion of several factories.

The drying of the perfectly washed gun-cotton is now the most dangerous part of the whole process of manufacture; it must be done with the greatest caution, and the temperature should not rise above 50° to 60° C.

In a well-managed factory, 100 parts of cotton yield from 155 to 175 parts of gun-cotton. Theoretically the yield should be about 185 parts. The following are some of the results obtained with 100 parts of cotton :—

Pelouze (1848)	168 to 170
Schmidt and Heckn (1848)	169·0
Van Kerckhoff and Reuter (1849)	176·2
W. Crum (1850)	178·0
Redtenbachn, Scrotter and Schneider (1864) .	178·0

Gun-cotton distinguished from Collodion-cotton.—Explosive gun-cotton is easily distinguished from collodion-cotton by its *insolubility in alcoholic ether.* It is shown by experiments, the results of which are given in the table below, that it is necessary in practice to avoid a dilution of the acid mixture.

Acid Mixture.	Parts of Water.	No parts of compound obtained from 100 parts cotton.	Nature of the compound.
Equal parts of Nitric and Sulphuric Acids . . .	..	177·0	Insoluble.
Do.	1	176·0	Do.
Do.	1¼	171·7	Slightly soluble.
Do.	1⅓	166·4	Entirely soluble.
Do.	1½	160·5	Do.
Do.	2	157·0	Easily soluble.
Do.	2½	140·0	Very easily soluble.

By an increase of the proportion of water the proportion of product obtained is lessened.

Gun-cotton an Ether of Nitric Acid.—Neither gun-cotton nor collodion-cotton is in an exact sense a nitro-compound, such for example as picric acid is, but they are rather ethers of nitric acid. This conclusion is based upon the chemical behaviour of gun-cotton with concentrated sulphuric acid and alkalies. Concentrated sulphuric acid in the cold sets the nitric acid free from the gun-cotton, and moderately concentrated potassium or sodium lye forms slowly at ordinary temperature, very quickly at 60° to 80° C. from the gun-cotton nitrates of potassa and soda respectively. These chemical operations, Böckmann claims, can be clearly accounted for only on the assumption that gun-cotton is an ether of nitric acid. Nitro-glycerine also gives by treatment with potassium or sodium lye the corresponding nitro-salt and glycerine, and therefore it also is an ether of nitric acid.

Calloxyline, or collodion-cotton, will be discussed further on (p. 95).

Many changes and improvements have been made in the course of time in the manufacture of gun-cotton. Here it will be sufficient to give in some detail two illustrative examples of the process—namely, the course of manufacture at Le Bouchet and Waltham Abbey respectively.

Manufacture of Gun-cotton at Le Bouchet.—At Le Bouchet, gun-cotton was made in the following manner. Two hundred grams of cotton were steeped for an hour in two litres of a mixture of one volume of concentrated nitric acid and two volumes of concentrated sulphuric acid. Then the cotton was taken out and pressed, whereby seven-tenths of the mixture was recovered; after this it was washed for one to one-and-half hour in running water; strongly pressed again; allowed to lie for twenty-four hours in wood-ash lye; then well washed in running water; then pressed and finally dried on a wide linen sheet through which was forced air heated to 60° C. The average yield from 100 parts of cotton was 165 parts of gun-cotton. The strong pressings of the gun-cotton while still impregnated with acids caused the subsequent washings to be difficult and laborious. By the Lenk process strong pressing is entirely avoided.

This process has been thus described :—

The cotton, in loosely twisted threads of various spun dimensions and formed into skeins of 85 grams weight, is hung in little hooks in a boiling potash solution of 1·02 sp. gr. to free it from fatty substances. After the cotton has remained in this solution for two or three minutes it is freed from the solution in a centrifugal machine.

Fig. 9 represents a centrifugal drier, the invention of M. Fesca. It consists of an open drum *a* of fine meshed wire-work caused to revolve in the cast-iron case *b b*, by means of the bevel-wheel *c d*, gearing with a motive power, the drum making 1000 to 1500 revolutions per minute. The motion of the drum can be stopped by means of the brake *e*, and regulated by the weights placed at *o*. The substance to be dried is placed in the drum, which, being set in motion, the liquid is by centrifugal force driven through the sieve, the dry substance remaining. The action of the machine is aided by the cone *g*.

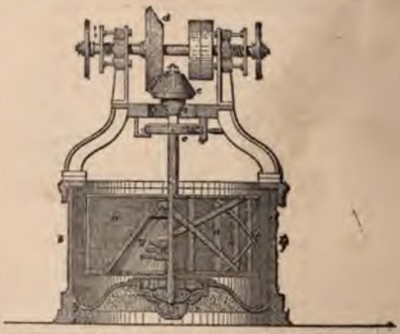

FIG. 9.—FESCA'S CENTRIFUGAL HYDRO-EXTRACTOR.

Fig. 10 shows a machine with an inner cylinder *m*, and an outer one, both revolving in concert and driving outwardly the liquid to the chamber *A* from which it trickles through a discharge pipe. The wet substance is placed around the cone *B*.

The cotton is taken from the centrifugal machine, washed with water, again whirled in the machine and thoroughly dried.

Nitric acid of at least 1·48 to 1·49 sp. gr., and sulphuric acid of 1·835 sp. gr., flow in thin streams from delivery cocks into an earthen vessel and become mixed in the proper time by weight of 1 to 3. The mixture is allowed to cool before being used.

Two of the skeins with 300 parts, by weight of the acid mixture, are placed together in a cast-iron tube-like steeping apparatus, gently stirred, and pressed with a shovel.

FIG. 10.—CENTRIFUGAL HYDRO-EXTRACTOR.

The cotton, when completely impregnated, has a fatty appearance.

When the point of saturation is attained (after a few minutes) the skeins are placed on gratings over reservoirs and the surplus acid allowed to drip off. This dripping is accelerated by gentle pressure on the cotton. One part of cotton will after this process have increased to at least 9½ parts. When about 2 kilograms of cotton have been steeped the acid mixture is entirely renewed.

FIG. 11.—STONE JAR.

When six skeins have been prepared (which should then weigh about 5½ kilograms) they are placed in a stone jar (Fig. 11) to remain from twenty to forty-eight hours. A cloth is placed over the skeins and held down by a light weight, in order that the skeins may be kept under the impregnating acid. During this time, in which the transformation of the cotton into gun-cotton is completed, the jar stands in a place the temperature of which is not allowed to pass below 5° or above 25° C. In winter, therefore, heating, and in summer sometimes cooling by means of running water, is necessary. During the first two to six hours the jar must be watched so that any possible heating may be prevented by seasonable cooling. After remaining in the jar for the proper length of time, the crude gun-cotton is freed from surplus acid in the centrifugal machine, then washed with a large quantity of water in copper washing drums and finally subjected for from three to six weeks to the action of running water in so-called "wool washing vessels." The gun-cotton cleaned in this way is treated with a boiling potash-solution of 1·02 sp. gr., then whirled in the centrifugal machine, washed again with water, again whirled, and then dried by a heat of 25° C. in the air.

When the last remaining acid has thus been removed the gun-cotton is steeped for a time in a sodium-silicate solution of 1·072 sp. gr. When taken out it is whirled and then exposed to the air for three days. During that time, the silicate of soda is decomposed by the air, and an insoluble silicate is precipitated on the fibres of the cotton. This is the so-called "silicate process."

In conclusion, the product is again washed in the softest possible running water, then whirled and dried, by a heat of 35° at the most, in the open air or in a drying-room.

Direct rays of the sun are to be avoided.

The average production after many years' experience is 165 to 167 parts of the explosive from 100 parts of cotton. The gun-cotton thus made was subjected to careful tests as to its structure and by means of an eprouvette as to its strength. Skeins with broken threads were discarded as unfit for use.

The above described Lenk method of making gun-cotton is in its essential outlines retained in this country at Stowmarket, but all the improvements introduced by Sir Frederick Abel have been added.

nufacture of Gun-cotton at Waltham Abbey.— ufacture of compressed gun-cotton has been actively pursued at Stowmarket, and at the Government factory at Waltham Abbey, since the commencement of 1872. The following is a brief outline of the process :—

Carding the Cotton.—The clippings and other waste from cotton mills (of the description in general use for cleaning machinery), after purification from oil and fatty matters by treatment with alkali, and removal of other extraneous substances, as pieces of string and rag, are passed through a machine somewhat similar to a carding engine for the purpose of opening up the material, and subsequently through a cutting machine to reduce it to a suitable condition for ready immersion in the acid.

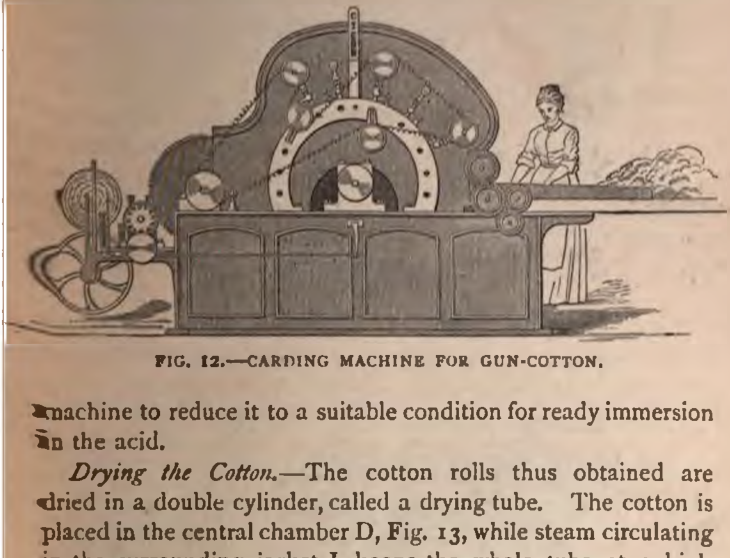

FIG. 12.—CARDING MACHINE FOR GUN-COTTON.

Drying the Cotton.—The cotton rolls thus obtained are dried in a double cylinder, called a drying tube. The cotton is placed in the central chamber D, Fig. 13, while steam circulating in the surrounding jacket J, keeps the whole tube at a high temperature. By means of a blower attached to the pipe P, a blast of air enters the outside chamber at the bottom; and heated as it is during its passage to the top, is led to the central tube and forced through the loose mass of the cotton. The latter is in this way rapidly robbed of its moisture, and when completely dried is placed in large tins and carefully covered.

After standing in these till quite cold, the cotton is weighed out in quantities of 1 lb. each, and carried by a boy to the dipping vessel.

FIG. 13.—DRYING CYLINDER AND SECTION OF DRYING TUBE.

Steeping the Cotton.—The contents of each box are separately immersed, by small quantities at a time, each pan containing a mixture of about 12 gallons, made up of 3 volumes of sulphuric acid, specific gravity 1·84, and 1 volume of the strongest nitric acid, the whole being kept cool during the action by currents of cold water, which circulate round the vessel. In this mixture the cotton is dipped, and after it has been in about three minutes, the workman lifts it on to a grating, just above the acids. Then, with a movable lever, he gently squeezes it until, roughly speaking, it retains about ten times its weight of the liquid. In this condition it is transferred to earthenware pots (Fig. 11) closed with well-fitting lids, in which it remains for twenty-r hours, these pots being placed into a shallow artificial

FIG. 14.—DIPPING AND PLACING THE STEEPED COTTON IN POTS.

basin, where cold water is made to circulate around them continually. The chemical change in the cotton is now complete.

Whirling out the Acid.—The large excess of acid which the cotton contains is got rid of by placing the cotton into a centrifugal hydro-extractor, as described in Figs. 9 and 10, and the waste acids discharged from these machines are collected in the waste acid tanks.

Washing the Cotton.—On leaving the centrifugal machine the gun-cotton has to be washed—an operation which requires great care, because the acids which the gun-cotton yet retains would give rise to a considerable development of heat if mixed slowly with water. At such an increased temperature the gun-cotton would be decomposed, or "fired," as it is technically called. At Stowmarket an artificial cascade is made by leading a stream of water along a trough, and allowing it to fall from a height into the washing vessel, Fig. 15. The gun-cotton is thrown on the falling stream, and is immediately carried deep down into the vessel, the agitation of the water being further promoted by the workmen. In this way the cotton comes in contact with such a large quantity of water that the rise of temperature is inappreciable, and the pyroxyline becomes almost altogether free from acids.

FIG. 15.—WASHING THE GUN-COTTON.

But to perfect the washing, the pyroxyline is passed through the centrifugal hydro-extractor, and then thrown into tanks, where it is subjected to the action of water for one, two, or three weeks, and afterwards boiled in large vats by the injection of steam; but the temperature of the boiling wate [illegible] should not exceed 100° C. The soluble impurities of [illegible] character, produced by the action of the acid upon [illegible] quantities of resinous and fatty substances which existed in [illegible] fibre, are very effectually extracted by this treatment, and t[illegible] gun-cotton, after a further rinsing, is then transferred to [illegible] beating or pulping engine, of a kind ordinarily used by [illegible] makers, for preparing paper pulp; it is technically termed

FIG. 16.—SECTION OF HOLLANDER OR PULPING ENGINE.

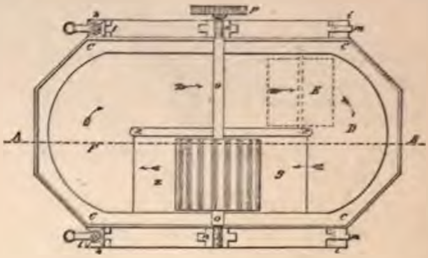

FIG. 17.—PLAN OF HOLLANDER.

"hollander." There it is brought into a state of fine subdivision, which is necessary for the subsequent transformation into a homogeneous compressed mass. Figs. 16 and 17 represent respectively a section and plan of a half hollander.

"The chief characteristics of the hollander are: 1. Speed of revolution of the trimming knife. 2. The box of knife edges under the revolving cylinder. 3. The trough and revolving cylinder. 4. The cap or partition above the trough to prevent the mass being cast out when in motion. The trough C, C is a long oblong cistern of cast iron, stone, or wood lined with lead. The cover rests upon a partition *x*, *x* of equal height with the outside wall. The machine is divided into two parts, the working side in which the rags are torn or shredded between the knife edges in the cylinder and those in the box, and the running side into which the shredded rags are thrown by the revolving cylinder. Under the cylinder is a massive oak block *t*, *the craw*, its concave surface comprising the fourth part of the circumference of the cylinder. The side *y* is a little and *z* much inclined. Half-way between *h*, *i* are two strong beams *l*, *m*, supporting the metal bearings in which works the axle *o*, *o* of the cylinder. From the roller Q a number of cutters run parallel to the axis. The knives are of soft steel, and in the whole hollander sometimes bronze. Beneath these a series of knives is placed, against which the rags are drawn by the cylinder. In order that by the movement of the cylinder none of the material should be thrown out a cover is provided, the dirty water thrown up falling through the sieve *u*, *u*, and flowing through the opening *g*, *g*. Clean water flows in from the top of the hollander. The washing finished, the water-pipe is shut by means of a sliding partition, each partition having an inner one to prevent the pulp passing away. The rags are poured into the top of the hollander with the requisite quantity of water. The roller revolves 100 to 150 times a minute, the knives cutting more readily in the fluid. Having passed the cylinder and the lower set of knives, the mass flows over the steep slope of the craw *z*, while the roller continues its work." In a similar manner the gun-cotton is drawn between the knives and reduced to a state of pulp. The bottom of the tub is movable, and thus the space through which the gun-cotton must pass may be contracted as the operation proceeds. The pulping completed, the contents of the hollander are run into a "poacher."

The poacher is a washing machine, similar in construction to the so-called "poaching engine" in common use at paper mills (see Fig. 18). Here the water in which the gun-cotton has been pulped is first drained off, and the pulp is very thoroughly washed by being continuously agitated together with a large volume of water for several hours, until, in fact, samples collected at intervals satisfactorily pass the heat test for purity. In the poacher, the pulp is agitated with a large quantity of water by a wheel. A strainer at the bottom of the poacher enables the workman to draw off the water and replace it by a fresh supply, in which the gun-cotton is washed.

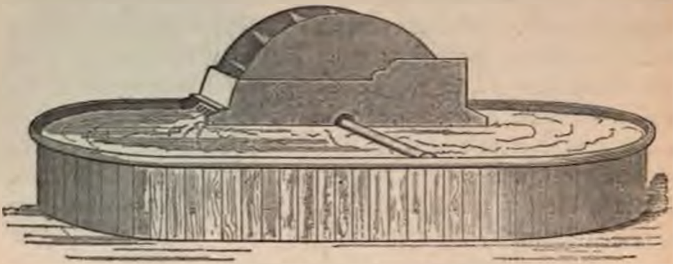

FIG. 18.—POACHER FOR WASHING GUN-COTTON PULP.

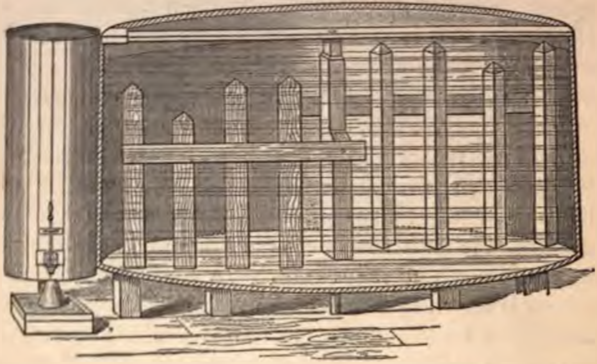

FIG. 19.—VAT OR MIXING MACHINE.

This final washing process secures a high degree of uniformity in the explosive power of the finished product, as 1000 lbs. of gun-cotton are washed in one operation, and the products of many hundred distinct converting operations are thus thoroughly mixed together.

The pulp is now transferred to the *vat or mixing machine*

(Fig. 19), and mixed with 2 per cent. of alkaline carbonate, when it is ready for the final operation.

Compressing the Gun-cotton.—The further processes of abstracting the water and moulding the pulp into given weights and shapes are performed in hydraulic presses of various kinds. Figs. 20 and 21 show the cylinder of the press and also the ram.

There are numerous devices employed for compressing gun-cotton, and among them are cylinders movable round a vertical support, and having a closely perforated plate fixed on their bottom ends.

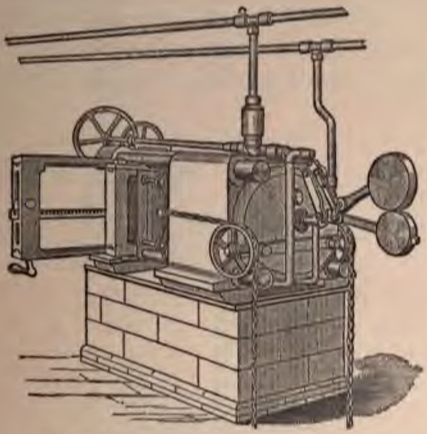

FIG. 20.—HYDRAULIC PRESS.

The cylinder being brought into the proper position, a measured quantity of the pulp is poured down a pipe. By the action of a suction pump connected with a tap, most of the water is at once drawn off through the perforated bottom of the cylinder. The latter is then turned round to the position, and the press set to work. In a very short time the gun-cotton is taken out in the form of a slab or cylinder. These are further pressed in a more powerful machine, as shown in Fig. 21, and afterwards soaked in water till they contain about 25 per cent. of that liquid.

Granulating the Gun-cotton.—Under the specification of Sir Frederick Abel, the gun-cotton is sometimes granulated by the following process:—

When the gun-cotton in the poacher has been washed sufficiently to pass the chemical tests for purity, it is placed in a centrifugal machine similar to that used for the purpose of extracting the large excess of acids after the conversion into gun-cotton. In this machine the pulp loses water till it contains only about 33 per cent., and is reduced to a condition more or less fibrous. It is then taken to the granulating room, where it is first passed through sieves or perforations, which break up the mass, and to some extent determine the ultimate size of the granule. The material is then transferred to a revolving drum, like a large barrel mounted on a horizontal axis, in which it is kept revolving for about a quarter of an hour. Water is from time to time sprinkled on the granules, or the sides of the drum are moistened, to assist the hardening

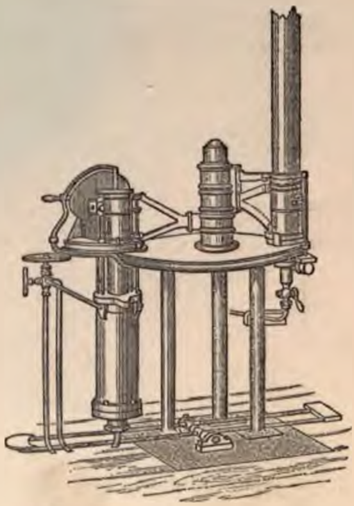

FIG. 21.—HYDRAULIC PRESS.

action. The drum, in revolving, carries the granules partially round with it, but under the action of gravity they descend after reaching a certain point, and thus are caused to roll over one another. The speed of the drum decides, to a great extent, the rapidity of the granulating process. The speed should be just such that the material is carried by the drum sufficiently forward on the surface to be compelled to run down sharply. On the other hand, it must not be too great, as none of the granules must be carried round by the centrifugal force of the drum. On removal from this machine, the completing operation is the removal of the water either to dryness or to the extent desired in properly arranged drying chambers.

CHAPTER VIII.

PROPERTIES OF GUN-COTTON.

Physical Appearance of Gun-cotton—How does Gun-cotton explode?—How to render it less sensitive—Detonation of Wet Gun-cotton—Gases produced by the Explosion of Gun-cotton—Spontaneous Decomposition—Advantages and Disadvantages of Gun-cotton in use.

In outward appearance cotton does not change on its conversion into gun-cotton, notwithstanding that very remarkable chemical changes have taken place in its nature. In fact, gun-cotton can hardly be distinguished by outward appearance from cotton. At the most it is rather less white, it generally feels somewhat harsher to the touch, and it grates slightly in squeezing it. It is heavier than cotton. Viewed under the polariscope the threads of gun-cotton are indistinct and exhibit little or no colour, while the threads of cotton are very distinct, and exhibit the most beautiful play of colours. Gun-cotton, however, can be easily distinguished from cotton by rubbing, when the former, particularly in moderate heat, will become strongly electrified, so that the threads will stick in lumps between the fingers of a dry hand.

How does Gun-cotton explode?—Gun-cotton will explode from a blow or impact of hard bodies, by heating to a certain temperature, and particularly by ignition. If it be subjected to a blow or impact of a hard body, an explosion as a rule ensues. The explosion, however, does not extend to the whole mass, but only to the portions directly struck. The threads which are not struck fly off intact. Sir Frederick *Abel found that,* when an explosion was caused by the blow of a hammer or by the fall of a weight, only a small portion of the mass was detonated, the remainder being scattered by the gases developed at the moment of explosion of that portion of the mass directly struck. This was the certain deduction from a series of experiments, most carefully made with cylinders or disks of compressed gun-cotton of equal weights and diameters subjected between polished brass plates on an anvil to the impact of a 22·7 kilograms weight, falling from a fixed height between leaders. When the weight fell from a height of 914 millimetres the gun-cotton was compressed to one-half its original length without explosion. The fall from a height of 1·828 metre produced a slight detonation by which the greater portion of the gun-cotton was scattered about. By a greater fall a somewhat larger portion was detonated, but even by the fall from the greatest attainable height of 11·883 metres, only a small portion was detonated, the remainder being scattered about.

How to render Gun-cotton less sensitive.—Gun-cotton, when saturated with a liquid or with a body which is solid at ordinary temperature, but added to the cotton in liquid form, is less susceptible of detonation than when mixed with a corresponding proportion of a solid body. The inert liquid envelopes each little portion of the gun-cotton, isolates it from the adjacent portions, and thus establishes a strong resistance to the propagation of the explosion.

The absorption by gun-cotton of 3 per cent. of water, in addition to the 2 per cent. which it contains in its normal condition, renders detonation by the ordinary agents uncertain.

Detonation of Wet Gun-cotton.—*Mr. Brown* (an assistant of Sir Frederick Abel) conceived the idea in 1874 of using *dry* gun-cotton to detonate wet compressed charges. According to his experiments gun-cotton containing as much as 17 per cent. of water is easily detonated (although not with absolute certainty) by the explosion of 6·6 grains of air-dried compressed gun-cotton when the initiating explosion was produced by fulminate of mercury. It must be in direct contact with the dry cotton. If the amount of water be increased to 20 per cent. detonation does not surely follow the use of 31·2 grains of air-dried cotton as the primer, and if the amount be increased to 30 to 35 per cent., which is generally the maximum amount that the gun-cotton will absorb, one cannot count with certainty in the detonation when less than 112 grains of air-dried cotton are used in direct contact. Wet compressed gun-cotton will be more easily detonated when dry gun-cotton and fulminate of mercury are used, than when the fulminate alone is used. The mixture of compressed gun-cotton and nitre or potassium chlorate is in a moist state and under otherwise similar conditions as susceptible of detonation as ordinary compressed gun-cotton, and the mechanical effects produced are the same. Compressed and wet gun-cotton which has been allowed to freeze is as susceptible of detonation as the mixture of gun-cotton and crystallized salts.

By heating gun-cotton, explosion is produced accompanied with brilliant flames and a hissing sound, but without a loud report. The temperature required for the explosion depends upon the quality of the gun-cotton and upon the rapidity with which it is heated. If it be heated very gradually it will decompose at 60° C., giving off acid fumes, but as a rule it will not explode under 130° C. Nevertheless, it sometimes explodes at much lower temperatures. Explosions have taken place when it was dried to 70° to 100° on sheets of metal. It has also been exploded by air heated from 25° to 80°. By rapid heating it will explode between 136° and 180°. It explodes more quickly and at a lower temperature than gunpowder. It can therefore be burned on the latter without the powder taking fire. The following is a very interesting experiment: On a piece of paper lay some gunpowder, on the latter lay a small portion of gun-cotton, and hold the whole about a foot above the flame of a lamp. The radiating heat of the flame will be sufficient to ignite the gun-cotton, while the powder lying under it and nearer to the source of heat will remain entirely unchanged.

Under pressure combustion takes place more gradually. *In vacuo* and also in nitrogen, hydrogen, carbonic acid or carbonic oxide gas, very small quantities of gun-cotton threads, ignited by very fine platinum wire heated by electricity, burn gradually with a greenish phosphorescent light. By increasing the pressure a slightly yellowish flame appears with the greenish light, and increases in intensity with increased pressure, until finally it passes into the brilliant orange flame of quickly burned gun-cotton.

Wet compressed gun-cotton burns up quietly in the open air. If it contain 12 to 14 per cent. of water it is ignited "with much difficulty in applying a highly heated body. As it leaves the hydraulic press upon being converted from the pulped state to masses, it contains about 15 per cent. of water; in this condition it may be thrown into a fire or held in a flame without exhibiting any tendency to burn; the masses may be perforated by means of a red-hot iron or with a drilling tool, and they may with perfect safety be cut into slices by means of saws revolving with great rapidity. If placed upon a fire and allowed to remain there a feeble and transparent flame flickers over the surface of the wet gun-cotton from time to time, as the exterior becomes sufficiently dry to inflame; in this way, a piece of compressed gun-cotton will burn away very gradually indeed."

A rifle bullet shot through it will not cause explosion. "If it be fired, however, by a strongly charged percussion cap, it will explode with great violence."

Gases produced by the explosion of Gun-cotton.— The combustion products *in vacuo* are carbonic oxide, steam and nitrogen; in the open air the same gases with a nitro-acid and cyanogen.

One pound of gun-cotton gives in combustion about 22,165 cu. in. of gas and produces the effect of from 4 to 6 pounds of gunpowder. *Drinker* says: "As to the gases evolved by combustion, it is said that from one gram (0·035 oz. avoir.) of gun-cotton there are evolved at combustion *in vacuo* in round numbers 588 cu. cm. (35·87 cu. in.) of gas, measured according to Hecker and Schmidt at a temperature of 32° F. (0° C.) and a barometrical height of 760 mm. (29,922 inches). Károlyi found at a temperature of 32° F. (0° C.) and a barometrical height of one metre (3281 ft.) (hence under high pressure) 574 cu. cm. (35,014 cu. in.) of gas.

"Blondran obtained from one gram (0·035 oz. avoir.) of gun-cotton saturated with ammonia 955 cu. cm. (58·25 cu. in.) of gas, and other statements go as far up as 1200 cu. cm. (73·2 cu. in.).

"The temperature of combustion of the gases amounts in round numbers to 8132° F. (4500° C.)."

The *chemical constituents of the gases* evolved on combustion are, according to *Károlyi* (in percentage of volume):—

	In vacuo.	Under high pressure.
Carbonic oxide	28·55	28·95
Carbonic acid	19·11	20·82
Fire-damp	11·17	7·24
Nitrous oxide	8·83	..
Nitrogen	8·56	12·67
Steam	21·93	25·34
Hydrogen	..	3·16
Carbon in excess	1·85	1·82

If the combustion take place under high pressure, the nitrous oxide entirely disappears from among the explosion gases, and in its place is formed a greater proportion of carbonic oxide, carbonic acid, steam and nitrogen.

Trauzl says that, "assuming 4500° C. (8132° F.) as the temperature of gases of combustion of gun-cotton, the theoretical maximum pressure in atmospheres 15,300, and the theoretical power in kilograms equals 200,000."

The explosion gases are, in consequence of the large proportions of carbonic oxide and fire-damp, easily ignited, and burn with a blue flame. In consequence of the large proportions of carbonic acid and carbonic oxide they are poisonous, and assail the eyes quite strongly.

Spontaneous decomposition begins with the evolution of gases (for example, gas of a nitro-acid); the gun-cotton gradually diminishes considerably in volume; and the residue contains small portions of a nitrogenous substance, traces of formic acid and acetic acid, also sugar, oxalic acid, and so-called gums. This decomposition appears to take place only when the cotton has not been sufficiently freed from fats, and the gun-cotton has not been completely disacidised. Lenk's gun-cotton, which, as is known, was produced in a high degree of cleanliness, was, according to Sir Frederick Abel, absolutely durable. Sunlight, although acting for a long time on Abel's gun-cotton, did not affect it. It is also not affected by quick heating to 90° C. Sir Frederick Abel heated boxes filled with gun-cotton for six minutes to 50° C., and no decomposition took place. He claims that this result settled the great and vital question of the durability of pure gun-cotton.

To increase its durability it has sometimes been impregnated with a soluble silicate, or with paraffin.

Advantages and Disadvantages in use.—The chief advantage of gun-cotton is its comparative insensibility to shocks, in consequence of which it is safe from explosion by hostile bullets or sympathetic explosion; but nitro-gelatine is also insensible to water, hostile shots, or sympathetic explosion, besides being very much stronger than gun-cotton.

The failures to introduce pure gun-cotton as a substitute for gunpowder in small-arms have already been alluded to (see page 55). But when diluted and mixed with certain other ingredients, its action is so modified that it can be used as an explosive in fire-arms. Gun-cotton is the agent most extensively used for all kinds of military engineering and submarine operations in Great Britain, being especially manufactured by the Government for that purpose. But it is not now so extensively used by civilians as formerly. Frost has no effect on dry gun-cotton, but causes a mechanical disintegration of the wet compressed variety.

Gun-cotton as manufactured by the old system was not serviceable for guns and small-arms. The experiments made in various European countries soon after the discovery of gun-cotton showed that infantry guns which withstood the effects of 3000 shots with powder became unserviceable on an average after 500 shots with about equally effective charges of gun-cotton. Gun barrels which permitted a charge of 27·5 grams of powder were burst by a charge of 7 to 8 grams of gun-cotton.

Another disadvantage was that the manufacture of gun-cotton cartridges was very slow, because they could not, like gunpowder, be *measured*, but had to be *weighed*. But a greater disadvantage is its very rapid explosion. It belongs to the very disruptive class of explosives. Powder possesses a certain pliability, inasmuch as its ingredients may be so proportioned as to regulate the rate of combustion, and hence its fitness for ballistic work. The explosive gases of gun-cotton are instantaneously developed, they occupy instantaneously a very large space, but a *continuous* force is not exerted. The stiffness, too, of gun-cotton cannot well be diminished by artificial means.

In order to overcome the inconvenience attending this great disruptive force, attempts were made to regulate the velocity of combustion. The gun-cotton was carded together with ordinary cotton; it was worked up with paper material in the hollander; metal cartridges were used, the front end, which was to be ignited first, containing mining powder, the explosion of which was to overcome the inertia of the ball; in the other end was the gun-cotton, the explosive gases of which were to furnish the projectile force. For the Austrian batteries Von Lenk employed gun-cotton in the following manner:—

A fixed weight of spun gun-cotton was wound as a flat jacket around a hollow wooden cone or cylinder. The rear end was ignited. The wooden body prevented a rapid burning up in the first instant of time, since the ignition could be propagated only along the periphery. As soon as the tension of the gas reached a certain height, the wooden cylinders were burst, and the combustion was complete.

The cartridge made at Stowmarket contains an envelope of strongly compressed gun-cotton, which is covered over with a thin waterproof layer of gutta-percha. For blasting purposes the pulp is pressed into forms and pricked with punches, to produce cavities to increase the velocity of ignition.

Gen. Abbot experimented, at Willett's Point, with Abel's compressed gun-cotton, dry, containing also 25 per cent. of water, and granulated gun-cotton wetted to a like extent, all made at Stowmarket. He found no marked difference in strength between these varieties and conditions of gun-cotton, although the addition of water seemed to cause a small loss of about 2 per cent.; and that gun-cotton in the wet state was safe, but its disk or slab form inconvenient, and when granulated it was bulky.

In blasting operations, gun-cotton acts with considerably greater effect in hard than in soft or well-fissured rock. *Schoen* states that in soft rock it exhibits twice, in hard rock five to six times, the blasting effect of gunpowder.

It is insoluble in and unaffected by water; and as it can be fired wet there is no need of ever drying it. For firing it a "primer" is used, which consists of a cake of dry gun-cotton, to which is attached a fulminate fuze. This primer must be enclosed in a waterproof bag or box. Large charges of wet gun-cotton can be exploded in this way. It is not sensitive to friction. Dry gun-cotton is very hygroscopic. Compressed gun-cotton is stored in a wet state, but should not be exposed to a temperature that will freeze the water in the cakes. It is made into disks of various dimensions, or it may be pressed into slabs or blocks which may be sawn, cut, or drilled as desired. In the form of disks it stows badly, and it is desirable that a charge to be exploded should be as solid as possible.

Sir Frederick Abel's caution to keep gun-cotton in a wet condition is worthy of special attention, since in that condition it may be kept for years without decomposing, and is perfectly safe to handle.

CHAPTER IX.

VARIETIES OF GUN-COTTON AND OTHER NITRO-COMPOUNDS.

PYROXYLINE—Schultze's Powder—Lannoy's White Powder—Uchatius' White Powder—Nitric Acid and Sugar—Nitro-Mannite—E. C. Powders—Johnson's Powders—Punshon's Gun-cotton—Totten's Gunpowder—Tonite—Professor Attfield's Experiments with Tonite—General Abbot on Tonite—California Gun-cotton.

Pyroxyline.—This term may be used to designate all nitro-compounds resulting from the action of concentrated nitric acid on cellulose or wood fibre—as, for instance, cotton, paper, sawdust, straw, &c. Sometimes it is used to designate solely gun-cotton, and in that case *Collodion-cotton* (of which an account will be found in the next chapter) is called *Soluble Pyroxyline.*

In the present chapter will be found particulars of various substances sometimes classed under this term.

Schultze's Gunpowder.—This is practically a nitrated, purified, and pulped wood-fibre, formed into grains. It is now manufactured by the Schultze Gunpowder Company, who appear to have overcome the difficulties which beset the inventor in the early stages of its production. Their process consists in macerating soft timber of clean growth, which is chemically treated until all resinous and fatty matter is extracted, and pure, finely-divided cellulose remains. After drying, this is treated with acids, and thoroughly purified till it stands Sir F. Abel's heat test. The nitro-compound is then finely ground and waterproofed; the proper density is given to the particles, *and it is finally* dried and sifted.

The properties claimed for the powder are, that it gives less pressure on the powder chamber than ordinary gunpowder; that it is smokeless, its explosion-gases being very light; that, weight for weight, it has more than twice the *propelling* power of black powder, and that it leaves less residue in the gun-barrel; also, the residue being alkaline and dry, no corrosion takes place. Quickness of ignition and slowness of combustion are also claimed for it. This means that the primer ignites the powder readily, and when once ignited it burns slowly, which reduces the strain on the powder chamber.

Lannoy's White Powder.—Wood or sawdust is nitrated by treatment with strong nitric acid, and twenty-two parts of the resulting nitro-cellulose are mixed with sixty-five parts of sodium nitrate and thirteen parts of sulphur.

It is claimed that this powder rends rock without great shattering, and hence with but few flying fragments. It is difficult of ignition and burns slowly. The experiments made at Altenberg, near Aachen, did not prove favourable. It is very costly, and leaves on explosion a strong and stinking smoke.

Uchatius' White Powder.—Starch is of a composition similar to that of cellulose, and can also, by treatment with strong nitric acid, be converted into an explosive nitro-compound called *Nitro-starch.* Uchatius' powder consists of this latter substance. For its production he dissolved one part by weight of potato-starch in eight parts of fuming nitric acid, care being taken to keep the mixture cool. The thick fluid was poured in thin streams into sixteen parts of concentrated sulphuric acid, constantly stirred. The resulting jelly remained standing for twelve hours, and was then repeatedly washed alternately with pure water and a soda solution. Finally the white powder was dried by a heat of 50° to 60° C. It is strongly hygroscopic, and is too strong and rending in its effects for use in fire-arms.

Nitro-compounds also result from the action of nitric acid on the various kinds of sugar. Thus there is known a

Nitro-raw-sugar, with an alcoholic solution of which it was proposed to coat ordinary gunpowder in order to render it impervious to water, and also to increase its explosiveness. A *Nitro-milk-sugar* is also known as *Nitro-lactus.*

Nitro-mannite is obtained from the action of nitro-suphuric acid on the species of sugar of the mannites found widely distributed throughout the vegetable kingdom, but principally found in the manna ash.

The manna sugar is dissolved in four parts of nitric acid (kept cool) and English sulphuric acid is added until no further separation takes place. The separated product is well washed and dried by a heat of 40° C.

Nitro-mannite in a pure state exists in snow-white, needle-shaped crystals, which are soluble in hot alcohol and in ether. It is an extremely explosive substance, approaching in this respect fulminate of mercury. It is detonated by a moderate blow. Nevertheless it is not so sensitive to heat or friction as fulminate of mercury. It is easily ignited, but is not very dangerous to handle. It has been proposed as the safest filling for percussion caps. It is said to decompose on long storage.

E. C. Powders are known also as *Rifle Gun-cotton.* They are divided into two divisions, *Sporting Powder* coloured with aurine, free from mineral acid, dissolved in ether, alcohol, and benzoline; and *Rifle Powder*, coloured with picric acid (free from mineral acid) dissolved in the same solvent. They are small round granules coloured respectively orange and yellow, and consist essentially of diluted nitrated gun-cotton.*

Two samples gave :—

Nitro-cellulose soluble	27·95	21·79
,, ,, unsoluble	28·35	25·58
Cellulose (unconverted)	3·15	4·17
Nitrates of potassium and barium	37·80	38·32
Matters soluble in benzole	0·60	1·95
,, ,, alcohol	2·15	6·32
Moisture	—	1·87

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* 'Dictionary of Explosives.'

Johnson's Powders.—In these powders dinitro-cellulose or lower forms of nitro-cellulose are employed, impregnated with barium or potassium nitrates and incorporated with charcoal or other carbonaceous material. Two examples given in the specification consist of the following :—

	For military arms.	For sporting arms.
Nitro-cellulose	50 parts	50 parts.
Potassium nitrate	40 ,,	22 ,,
Barium nitrate	—	25 ,,
Torrefied starch or lamp-black	10 ,,	3 ,,

The powders are formed into grains, or blocks, and impregnated with a solution of camphor and phenol, or camphor alone, in a suitable volatile solvent, in the proportion of one part of camphor (or camphor and phenol) in five parts of solvent to ten parts of the powder. The solvent is driven off at a gentle heat, and the camphor is subsequently driven off at a temperature not exceeding 100° C.

It is claimed that by this method powders can be produced of any required degree of hardness and density, thereby regulating the energy of action of the explosive, and it is stated that "these results are obtained not by the presence of camphor in large or small quantities in the finished explosive, but by a remarkable gelatinizing and perhaps some other action exerted by the camphor upon the nitro-cellulose when these are heated together at varying temperatures up to 100° C., whereby the hardness and density of the explosive may be regulated at will by the proportion of camphor used."

Punshon's Gun-cotton was coated, covered, or incorporated with sugar, either raw or refined, in such a manner as to separate or isolate the particles or fibres of the gun-cotton and thus regulate the rapidity of the combustion. He also added nitre.

Totten's Gunpowder consists of grains, the kernel of which is pure gun-cotton. It is lighter than ordinary cannon powder, and is four and a half times more effective. The diameter of the kernel is thirteen millimetres, and the diameter of the entire grain is twenty-six millimetres.

Tonite.—Under this name is manufactured at Faversham, by the Cotton Powder Company, Limited, and at San Francisco, by the Tonite Powder Company, an explosive, into the composition of which gun-cotton enters very largely.

Tonite consists of finely divided or macerated gun-cotton, compounded with about the same weight of nitrate of baryta. At Faversham two qualities are made, known in the market as White No. 1 and Black No. 2. The White is composed of about 50 per cent. of gun-cotton and 50 per cent. of nitrate of baryta, while the Black has a larger proportion of baryta with a small percentage of charcoal.

The white is used for blasting hard stone, such as quartz, and where the object is to smash up as much as possible locally. It is essentially a "shattering" compound to be employed where a great local disruptive action is required.

The black is for use in softer stone, such as limestone, in quarries, where large blocks of building material are extracted. The explosion of this compound is therefore slower, and does *not* produce the sphere of pulverisation, only a middling-sized sphere of rupture, but a proportionately large sphere of fracture, therefore its application for quarrying stone is advantageous.

For the same reason it is used in torpedoes for submarine blasting in the removal of obstacles to navigation, such as destroying sunken wrecks, where the object to be gained is to shake and shatter the frame of a vessel to pieces, and therefore the area of disruption must also necessarily be a large one, so as to avoid multiplicity of charges. If the No. 1 white were to be employed for such works, its explosion would blow a big hole through the side of the vessel without breaking up the frame. But when it is a question of use for military submarine purposes, be it offensive or defensive, as in torpedoes, the No. 1 white has to be used, as it is quite sufficient to blow a big *hole through* the enemy's vessel (without shaking the frame), and to sink her, as the vessel can be raised afterwards and made use of again.

The No. 2 black being not so sensitive to detonation, the white tonite is used as a primer to give the initial detonation. In loading a bore-hole with the black, first insert the cartridges in the bottom, and the white is placed on top of the charge with the cap and fuze inserted. By using good caps or detonators, or strong electric exploders, no miss-fire need be apprehended.

The gun-cotton which is used in the manufacture of tonite is mainly common cotton waste steeped in mixed nitric and sulphuric acid; and on the excess of acids being forced out by hydro-extractors, it is left for some time for digestion, in stone jars, as already described elsewhere under the heading of manufacture of gun-cotton. Necessarily, while in the moist state, the fibres are macerated or disintegrated between crushing rollers. This perfectly purified macerated gun-cotton is intimately mixed up between edge runners with about the same weight of nitrate of baryta. This compound is then compressed into candle-shaped cartridges, formed with a recess at one end for the insertion of a fulminate of mercury detonator, and covered with paraffined paper.

Among the special advantages claimed for tonite are, that if it is wetted by accident, it can be dried in the hot sun or a warm atmosphere. The use of nitrate of baryta, a salt containing a great amount of oxygen in a very small volume, makes tonite a compound which readily explodes by the use of a proper detonator, while its great density makes it slow to the influence of ordinary combustion. Its great density causes it to burn slowly if set fire to, and so slowly that all danger from a too violent generation of gases is obviated. While, therefore, the railways of England refuse to carry dynamite, they regularly take tonite on the same footing as gunpowder. The tonite cartridges are generally waterproofed. The density is such that it takes up the same space as dynamite, and two-thirds of gun-cotton. It is also ready and available at any climatic temperature. It can be employed in wet holes, and can be tamped with water; but as all detonators are sensitive to moisture, they should be protected after insertion in the cartridge by tallow. The better the tamping the greater its effect.

Owing to the large proportion of the oxidising salt present in this compound, its detonation is perfect, and this accounts for the absence of noxious gases when it is used in close drifts and workings, and commends it for underground workings with bad ventilation.

The following report gives the results of experiments made with tonite by *Professor Attfield*, as a safety test:—

"1. A mass of iron, weighing half a ton, was let fall from a height of 15 feet on to a box containing 10 lbs. of tonite. It did not ignite the powder.

"2. An unusually well-made powder barrel, strongly hooped and headed, containing 30 lbs. of tonite in the form of cartridges of various sizes, was placed over some faggots saturated with tar, and a large bonfire kindled. In four minutes the cartridges ignited, and merely burned quietly for some 30 or 40 seconds. Every cartridge was entirely consumed without any explosion whatever.

"3. A box holding 10 lbs. of tonite was next fired into from a rifle, at a distance of about 20 yards. The bullet ignited the powder, which burned rapidly but quietly away without explosion.

"4. A cartridge was placed in an open box containing 2 lbs. of common gunpowder, and the latter fired by a fuze. The cartridge was blown some yards, but not exploded. The same cartridge was afterwards fired by the usual means.

"5. Strong sparks of electricity were next passed through some of the tonite without effect.

"6. Many blows of an iron hammer on an iron anvil failed to ignite portions of the powder, and when ignition was at last effected the adjacent portions of powder were merely blown on one side without being exploded.

"7. Concentrated acids (oil of vitriol and fuming nitric acid) were both successively and together poured on to portions of *the powder* without ignition.

"8. Lastly, to show the power of this patent cotton powder, when intentionally exploded by detonation, a 12-in. balk of timber was shattered by four small cartridges; a fountain of water 80 or 100 feet high was thrown up by the explosion of a floating box of the powder; and a hole in the marshes, 8 feet across and 4 feet deep, was instantly produced on exploding 1 lb. of the powder."

In a report made to the United States Government by *General Abbot* on the tonite manufactured by the Tonite Powder Company, he makes the following observations:—

"The standard tonite made by this company consists of 52·5 parts of gun-cotton and 47·5 parts of nitrate of baryta; but for special purposes and by request a part of the latter is sometimes replaced by potassium or sodium nitrate.

"At Willett's Point two varieties were received—one dry in compacted cartridges, and the other damp in bulk.

"The dry cartridges were $1\frac{1}{4}$, $1\frac{1}{2}$, $1\frac{3}{8}$, and $1\frac{3}{4}$ inch in diameter, and weighed from 3 to 12 oz. each. The smaller sizes were 3 in. long, and the largest 6 in. They were of two kinds, 'solids' and 'primers.' Both were encased in a paper wrapping compressed to a specific gravity of about 1·28, and coated with paraffin. The 'solids' were simple cylinders exposing plane ends; the 'primers' were similar in form, but they had a small hole at the top for receiving a fulminating fuze—for securing which the wrapping was extended into a short neck. The cartridges were such as are sold to miners.

"The damp lot was in the condition in which it is taken from the incorporating mill, and in which it goes to the press-room. In that condition it is supposed to contain 18 per cent. of moisture. It is slow to burn and difficult to detonate, and a compressed primer must be used with it in close contact. In this condition it is not sold at present to the company's customers. It would appear that the strength of the explosive is not reduced by moisture.

"The relative efficiency in a horizontal plane of tonite, as shown by Abbot's experiments, is compared to dynamite No. 1 for dry compressed variety as 0·81 to 1, and for the other as 0·85 to 1, or a mean of 0·83 to 1. The substitution of a portion of nitrate of baryta tends rather to reduce than to increase the normal intensity of action of gun-cotton, pound for pound, when fired under water, but this is not the case when fired in the open air or under confinement in rock."

The Home Office has lately granted a licence for a *Tonite*, or *Cotton Powder No.* 3, and its manufacture has been commenced by the Cotton Powder Company. Its composition is as follows:—

Gun-cotton.
Nitrate of potash.
Meta-di-nitro-benzole.
Nitrate of soda and chalk.

It is of a yellowish colour, and rather slower in its explosive action than tonite No. 1, and appears well adapted to blasting coal.

California Gun-cotton.—The Tonite Powder Company of San Francisco manufacture gun-cotton by a process which appears from its circulars to be essentially that of Sir Frederick Abel—omitting the compression into cartridges. It was delivered to General Abbot damp in the state of loose powder, which when dry became a fine dust.

It is claimed that the average product contains about 93 per cent. of insoluble nitro-cellulose and 7 per cent. of soluble gun-cotton, and when shipped contains about 24 per cent. of moisture. *Abbot* states that it may be confidently assumed that the gun-cotton made by the company is not inferior in explosive intensity of action to the best English manufacture.

CHAPTER X.

COLLODION-COTTON.

ITS importance in Practical Use—Processes of Manufacture—Compounds of Cellulose—Celluloid—Tribouillet and Besaueile's Process—Proportions in which Cellulose is found in Natural Products.

COLLODION-COTTON is a variety of nitrated cotton which has attained greater importance than gun-cotton itself through its diversified employment—for instance, in photography, for the preparation of the exposed plate; in blasting, for the production of explosive gelatine from nitro-glycerine; in surgery, for uniting the edges of wounds; and in the manufacture of "fancy goods," for the production of *Celluloid.*

It is really different from gun-cotton in its chemical nature, although the same raw materials serve for the production of both. Gun-cotton is extremely explosive, while collodion-cotton is very slightly so; the former is insoluble in alcoholic ether, while the latter is soluble in that menstruum.

Ménard and Flores Domonte were the first to obtain a gun-cotton soluble in alcoholic ether.

Béchamp investigated it, and found it to be dinitro-cellulose.

	Found.	Calculated.
Carbon	28·22	28·57
Hydrogen	3·57	3·17
Oxygen	57·43	57·15
Nitrogen	10·78	11·11

In 1847 there was imported into Germany from America a solution which bore the name of *Collodion*, and which performed excellent service in surgery.

It was soon found that not all gun-cotton was suitable for the manufacture of collodion, and that the most easily explosible was the most insoluble in alcoholic ether. Since the strongest nitric acid produced the strongest gun-cotton, it was concluded and shown that a cotton suitable for collodion manufacture was to be obtained by employing a less concentrated acid. It was also obtained by using potassium nitrate and sulphuric acid instead of the two acids, since in the former case the nitric acid was gradually evolved from the nitrate, and the action in the cotton was less energetic.

In 1851 *Archer and Fry* discovered their collodion process.

Manufacture of Collodion-cotton.—The following are brief descriptions of the principal processes:—

According to *Dawson*, particular stress being laid upon the quality of the cotton, the long-fibred varieties, such as Sea Island and Egyptian, are to be preferred.

According to *Mann*, good collodion-cotton is obtained in the following manner:—

Pour 31 parts of sulphuric acid of 1·83 sp. gr. over 20 parts of powdered potassium nitrate, stir until the nitre is dissolved, and after it has cooled to below 50° C. mix in 1 part of cotton; work the whole well through, cover the vessel with a plate, and let the mixture stand at a temperature of about 30° for about 24 hours; then wash the preparation with water; finally wash with warm water to remove all sulphate of potassa and dry. Many experiments conducted on a large scale have shown that the soluble collodion-cotton is formed in from 5 to 7 minutes, but that 5 to 6 days' action of the acid solution in the cotton is productive of good, as long as the temperature does not exceed 30° C.

According to *F. Luchs*, one steeps 1 kilogram of cotton in a solution of 20 kilograms of sulphuric acid and 9 kilograms of powdered potassium nitrate; lets it lie therein until a sample of the cotton taken out, washed with water, pressed, wetted with alcohol and again pressed, is easily and entirely dissolved in a mixture of 2 parts of ether and 1 part of alcohol. Then the preparation is thoroughly washed with water, pressed between linen cloths, alcohol poured over it until the yellow colour disappears, and again pressed for 24 hours. In summer the solution of sulphuric acid and nitre remains standing for some ten minutes before the cotton is steeped in it; in winter it is first heated slightly in order to prevent the separation of potassium sulphate. Instead of the salt, nitric acid may be used, provided the two acids be not too strong. Suitable proportions are 89 parts of nitric acid of 1·424 sp. gr., and 104 parts of sulphuric acid of 1·833 sp. gr.

Another recipe is as follows: 13 parts of sulphuric acid of 1·632 sp. gr. and 12 parts of nitric acid of from 1·512 to 1·518 sp. gr. are mixed and cooled to 5° C. In this mixture is steeped 1 part of cotton, care being taken that the temperature does not rise above 8°. After 24 hours' steeping the cotton is removed, thoroughly washed with water and dried.

Hager gives the following: Clean carded cotton is washed with a 3 to 4 per cent. solution of carbonate of soda and distilled water and dried. By simply dipping it into nitric acid of 1·4 sp. gr. it is transformed into colloxyline (collodion-cotton). Such an acid is not always to be obtained, and therefore its place is supplied by a mixture of dilute nitric acid and concentrated sulphuric acid or by a mixture of potassium nitrate and concentrated sulphuric acid. The time required for the change of cotton into colloxyline depends upon the strength of the nitric acid. The more concentrated it is, the quicker is the transformation accomplished. The colloxyline once formed, the same acid has no effect upon it. The temperature of the acid mixture must be lowered to a medium degree before dipping the cotton. A temperature of 30° C. is without any perceptible influence in the formation, as well as upon the gain in weight of the colloxyline.

At higher degrees other compounds of cellulose are formed, which may be enumerated as follows:—

1. *Pentanitro-cellulose.*—This is produced by the treatment of cotton with strong concentrated acid mixtures at low temperatures, and increase of the percentage of sulphuric acid assists in its production. The pentanitro-cellulose is never perfectly pure when produced in this manner, but contains some hexanitro-cellulose (gun-cotton) or tetranitro-cellulose; the former in case the acids were too concentrated, and the latter in case the acids were too dilute.

Pure pentanitro-cellulose can be obtained if collodion-cotton is dissolved in warm nitric acid and the clear solution is precipitated by means of a surplus of sulphuric acid; for this purpose, the collodion-cotton is put into nitric acid of a temperature of 40° to 60° C. and 1·40 sp. gr. till the solution takes a strong yellow colour, which is the case after heating the acid about one hour. After cooling the vessel in the air, it is introduced into a refrigerator surrounded with ice, and is then passed through an asbestos filter. The filtrate is cooled on ice again and four times its volume of concentrated sulphuric acid of 1·80 sp. gr., also cooled previously on ice, is added to it. The vessel should always remain in the refrigerator.

After the separation of the pentanitro-cellulose, the liquid is poured into a large volume of water, and the collodion-cotton is collected afterwards on a filter; for the further purification of the collodion-cotton, it is dissolved in a mixture of alcohol and ether, from which the same is separated by adding water.

2. *Tetranitro-cellulose* is produced by the treatment of cotton with a mixture of concentrated sulphuric acid and not too concentrated nitric acid, at a moderately high temperature. A mixture of one volume sulphuric acid of 1·845 sp. gr. and one volume nitric acid of 1·38 sp. gr. at 65° C., when acting on the cotton from 5 to 10 minutes.

3. *Trinitro-cellulose*, or rather a combination of tri- and tetranitro-cellulose, is obtained by the treatment of cotton with a mixture of sulphuric acid, and not too concentrated a nitric acid at a sufficient temperature; for instance, by taking a mixture of five parts of sulphuric acid of 1·845 sp. gr. and four volumes nitric acid of 1·38 sp. gr. at 65° C., and by letting it

act on the cotton from 5 to 10 minutes; or if cotton is acted upon during 15 minutes at a temperature of 80° Celsius with a mixture of equal volumes of sulphuric acid of 1·845 sp. gr. and nitric acid of 1·40 sp. gr.

4. *Dinitro-cellulose* is produced by the action of very dilute and hot nitric sulphuric acid on cellulose, and also by the action of potash or ammonium on ordinary collodion-cotton (on tetranitro-cellulose).

In this last manner a dinitro-cellulose is obtained, if 2 to 4 grammes of collodion-cotton are dissolved in 100 cubic centimetres of a mixture of ether and alcohol, and an alcoholic solution of potash added in excess. The collodion becomes very fluid and of a brown-yellow colour. After one or two hours it is diluted with water, and the free alkali neutralised with sulphuric acid.

The dinitro-cellulose collects on the surface of the liquid as a white, flocculent precipitant, which is filtered, washed and dried. The dinitro-cellulose is a yellow-coloured, gum-like mass.

From what has been said, it is evident that in the preparation of collodion-cotton a dilute nitric acid is employed, and that the nitrating has to be carried on at an elevated temperature, from 50° to 70° C.

The solubility of collodion-cotton varies with the quality A good product will dissolve in 7 to 8 parts of ether to which 1 part of alcohol has been added. The fluid so obtained has a syrupy consistency.

Celluloid.—The pyroxylines have been largely applied of late years in the production of celluloid from which (as intimated above) are made various fanciful imitations of ivory, horn, corals, malachites, *lapis lazuli*, amber, and the like. To enumerate, indeed, all the wares produced by it would furnish a very long list of *articles de luxe*.

Tribouillet and Besaueile's Process.—Messrs. V. Tribouillet and L. Auguste de Besaueile, of Paris, have introduced an improved method for the manufacture and treatment of pyroxyline, and for the production of a solid compound therefrom in association with camphor and like substances.

For the production of pyroxyline the raw materials employed are paper and rags of cotton, linen, and hemp fabrics thoroughly cleaned, and especially free from fatty matter; certain white woods, stalks of fibrous plants, such as esparto, which consist chiefly of cellulose, and contain few incrusting ingredients. The cellulose material is thoroughly dried in a stove at a temperature of 212° Fahr.; then disintegrated and bruised in a mill or other suitable apparatus, after which it is kept free from damp, and finally transformed into pyroxyle by means of the following apparatus:—

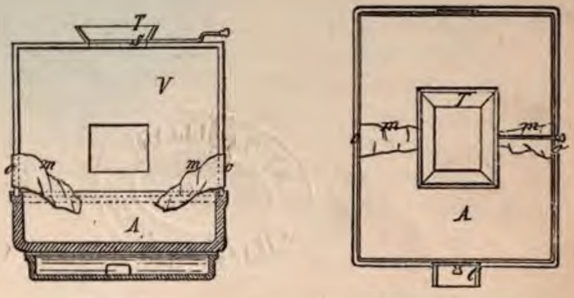

FIG. 22.—Section. FIG. 23.—Plan.

NITRATING BASIN.

There are required three basins A, a vertical section of one of which is shown at Fig. 22 of the accompanying drawings, and a plan at Fig. 23. Each of the basins may be made of one or more plates of glass, or plate enamelled with a glaze containing little alkali or lead to prevent it from being attacked by powerful acids. They might also be made of ceramic ware, or of thin cast-iron enamelled or not. Each basin rests on a lower basin made of wood or metal, through which circulates a gentle stream of water to the bottom of the basin A. Each basin is enclosed by a glazed cover V to prevent the weakening of the acids by access of damp air, and to protect the workmen from the fumes. This cover is surmounted by a hopper T closed at its bottom by a valve *s*, and it has a lateral orifice *c* opening like a window, and two circular orifices *o*, to which are attached sleeve tubes *m* of caoutchouc or gutta-percha, by which the arms of workmen can be inserted to agitate the contents. Two of the basins serve for treatment with acid, and the third for washing with pure water.

There are also required three cylindrical vessels, one of which is shown in vertical section and sectional plan at Figs. 24 and 25. The internal diameter is the same throughout, but the external diameter increases downwards. These vessels are made of cast-iron enamelled both inside and outside, and are perforated, and especially at the lower parts, with numerous small holes, permitting issue of liquid when the contents are subjected to pressure. The pressing piston P is of cast-iron enamelled, or of ceramic ware or granite provided with a rod *t*.

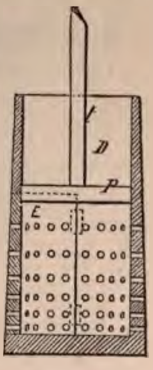

FIG. 24.
Section.

The material pressed in the cylinder is taken out by a door E extending half round the circumference, and about three-fifths of the height. This door is securely bolted to resist pressure. For each cylinder is required a screw press of any known kind. They act on the pistons of the vessels D, which are placed on a stage for the extraction of liquid from the material treated. Two of the basins of the cylinders and of the presses are employed for treatment of the cellulose with acids; the third of each for preliminary washing with water.

FIG. 25.—Plan.
CYLINDRICAL PRESS.

For the succeeding washings are employed wooden vessels F, shown in vertical section at Fig. 26. The bottom only is perforated with small holes, and covered with fabric G of cloth, felt, or the like, which acts as a filter retaining the pyroxyle. Under the filter is placed a receiver H of wood to receive the liquid, which has passed through the pyroxyle. The size and number of the washing vessels and receivers depend on the extent of the manufacture. The washing vessels may be arranged in stages, so that the liquid from each receiver may flow by gravity through the successive masses of pyroxyle. The washing vessels may in such case be of less height, as shown in Fig. 27, and may have unequal wheels, so that they may be placed on an incline, and run therefrom when the washing is completed.

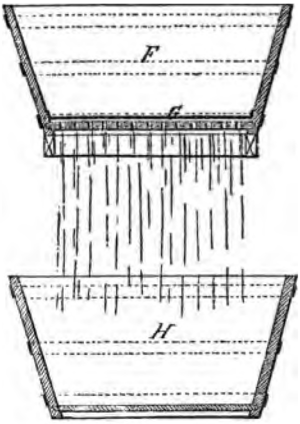

FIG. 26.—FILTER.

In conducting the manufacturing operations the acids employed are contained in close vessels placed at a higher level than the basins, so that their contents may flow into the latter by gravity. The acid vessels may be of enamelled iron, or of ceramic ware, or thin granite. The acid liquid consists of 3 parts sulphuric acid at 66° to 2 parts of the concentrated nitric acid of commerce. In the mixture is dissolved nitrous gas, which renders the pyroxyle more soluble.

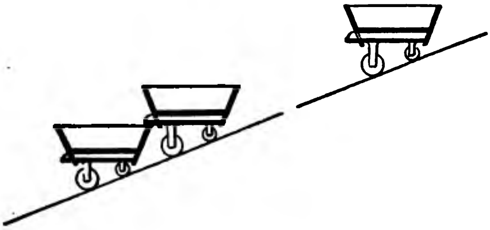

FIG. 27.—WASHING VESSELS.

Fig. 28 is a general plan of the arrangement of a pyroxyfactory. The acid mixture cooled to 45° to 55° Fahr.

is introduced into the second basin A^2 to a depth of an inch or more. Into the first basin A^1 is introduced a somewhat larger quantity of acid that has already been used, and in this is immersed the dry divided cellulose introduced by the hopper T, Fig. 22, in such quantity as the liquid will moisten. An operator then passing his arm into one of the sleeve tubes *m*, violently stirs the mass for 10 to 15 minutes, after which the whole contents are placed in one of the cylinders D^1; he then introduces the piston P, and puts the press X^1 in action. The liquid pressed out is received in a special reservoir. The press is then unscrewed, the piston is removed, and the pressed cake is taken out by the side door and plunged in the concentrated acid in A^2. A sort of trowel worked by the hands, inserted at the sleeve tubes, breaks up the cake. Stirring is continued until the cellulose is quite dissolved, the mass is discharged into the second cylinder D^2, and subjected to a considerably greater pressure than in the first cylinder. The acid liquids pressed out are charged into the first basin A^1 to act in the first place on the cellulose. The cake of pyroxyle remains impregnated with about one-third of the acid employed.

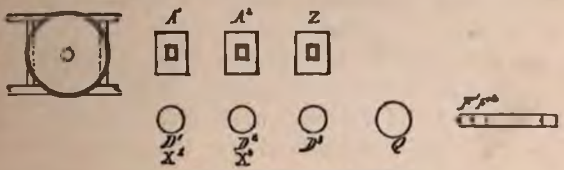

FIG. 28.—PLAN OF FACTORY.

Acid may be economised by employing a bath of that which has previously served, raising its temperature to about 50° Fahr., but the material must be kept for several hours in this bath. The temperature and the time of immersion may be reduced by adding to the bath that has served about one-third of its weight of a mixture of nitric and sulphuric acids, or sulphuric acid alone, or sulphate or bisulphate of soda, or any other sulphate soluble in water, adding it quite dry in powder. After its transformation into pyroxyle, the material is pressed as already described. The washing of the pyroxyline is intended to clear the nitrated cellulose from the acids which would destroy it and render it spontaneously combustible, and at the same time to collect those acids which if run to waste would be noxious. The first washing of the cakes charged with concentrated acid is effected in a basin Z, Fig. 28, like those employed for treating the cellulose; and it is then pressed in the cylinder D^3. For the second washing the cake is divided in a vat Q of wood, containing acidulated water, then the whole is charged into the first of the wooden filters F^1 mentioned above. The washing then proceeds methodically, that is to say, the first becomes the second F^2, then the third F^2, the first receiving the washing liquid from the second, the second from the third, and the last receiving pure water. The washing might, if required, be rendered more complete by employing three or four basins with a like number of presses.

Finally the material is washed in water containing a very small proportion of carbonate of soda or ammonia, or rather silicate of soda; and then with water only, the greater part of the moisture being then removed from the pyroxyle by means of a centrifugal machine or strong pressure. The pyroxyline is kept for further use immersed in water. The acids which cannot further serve for treating the cellulose may be employed for various purposes, particularly for the manufacture of sulphuric acid. The liquor from the washings can be used for the manufacture of oxalic acid, dextrine, pickling liquor, and other purposes. From the acid waste by saturation with carbonate of lime may be collected the soluble nitrate, to which may be added sulphate from the washing; the whole may be subjected to evaporation and disposed of. Or the nitrates may be treated with sulphate of potash or soda, so as to produce nitrates solidified by evaporation and crystallisation.

As the cost of pyroxyline is greatly enhanced by the large quantity of acid required for its production, it is of importance to economise this expenditure by mixing with the sulphuric and nitric acids that have been already used, and have consequently become weakened, a variable quantity of bisulphate and a little nitrate of potash or soda. These salts should be separately dried at a temperature which does not decompose them, and then pulverised. Sufficient concentration is thus obtained to enable the acids to be used several times in treating cellulose. For the alkaline, bisulphate and nitrate may be substituted, a proportion of nitric acid at 45° to 48° Beaumé, and sulphuric acid a few degrees above 66°. By treating the acids in either of these ways they become finally available for the production of nitric acid by adding the nitrate of potash or soda. The sulphuric acid assisted by heat dissolves the salt, leaving the nitric acid free, which is separated by distillation. Should it be preferred to prepare the pyroxyline by the old method, that is to say by treatment with a nitrate and sulphuric acid, the operation may be conducted as follows:—

The pulverised nitrate is mixed with the acid in a vessel, where after agitation the mixture is allowed to settle. The liquid portion is decanted into a vessel, where the cellulose is immersed in it. After removal of the pyroxyline, the liquid as well as the deposit is heated and treated in the usual way for production of nitric acid. The acid liquors, after having transformed cellulose into pyroxyline, may also be applied in the treatment of phosphate of lime, to produce a soluble biphosphate with sulphate and nitrate of lime.

The cellulose in the cheap condition of thin unsized paper, cotton waste, or rags, is treated in the known manner with suitable proportions of acid at the usual temperatures, and for the usual periods in apparatus consisting of a large basin heated by steam-pipes at the bottom, and a number of baskets or vessels of enamelled wire or perforated plate, or of ceramic ware. One of these vessels is shown in sectional plan at Fig. 29. It is of segmental form, with its sides perforated. This being charged with the cellulose in a state of division, is immersed in the acid bath and agitated. After the cellulose is transformed into pyroxyline the vessel with its contents is placed in a sloping position to let it drain, and then a number of the vessels are

FIG. 29.
ENAMELLED WIRE BASKET.

placed on a centrifugal machine for the more complete expulsion of moisture. After this, the vessels are plunged in a basin containing the acidulated water coming from the other basins.

All this apparatus is arranged within a glass chamber, the manual operations being effected by means of flexible sleeve tubes, as above described, attached to holes in the sides of the chamber. The vapours are conducted from the chamber to a condenser. The vessels or baskets containing the pyroxyline to be washed are introduced successively into basins mounted on trucks, the washing being carried on methodically, that is to say, when the first vessel or basket is taken from one of the basins, the second takes its place, and so on.

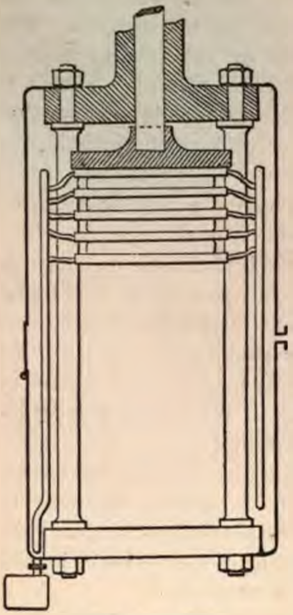

FIG. 30.—PRESS.

The pyroxyline is bleached by permanganate of potash and sulphurous acid. For 4 cwt. of pyroxyline about 1 lb. of permanganate is dissolved, mix the whole with 2 to 3 tons of water, agitate and blow through the mass a current of sulphurous acid till the bleaching is complete. This may be done in a vat with revolving agitators or in a rag mill, whereby the pyroxyline is at the same time reduced to pulp. Instead of the current of sulphuric acid, sulphuric acid and salt may be employed, mixing about 150 lbs. of the former and about 60 or 70 lbs. of the latter with the mass containing the permanganate; or instead of these materials about 5 lbs. of hyposulphite of soda, with about 50 gallons of water, and 11 lbs. of hydrochloric acid may be added slowly to the mass under agitation, causing the colour given by the permanganate *to disappear* entirely. Hyposulphite alone may be used for bleaching, or for final bleaching after a preliminary bleaching, as above described.

The apparatus employed in compounding the pyroxyline are as follows:—1. A paper or rag mill or beater to bruise the pyroxyline and camphor. 2. An apparatus similar to the heated presses used for the manufacture of stearine with the following modifications, as shown in Fig. 30. The cakes, rectangular, square, or round, are placed horizontally, to avoid a preliminary pressure which solidifies the mixture of camphor and pyroxyline; the press, which may be a screw or hydraulic, is entirely surrounded by a casing of plate provided with a door. The rod of the press passes through a stuffing box in the casing, at the side of the casing an opening connected to a coil for condensing vapours a chamber with which the coil communicates for receiving the condensed camphor and other solid matters.

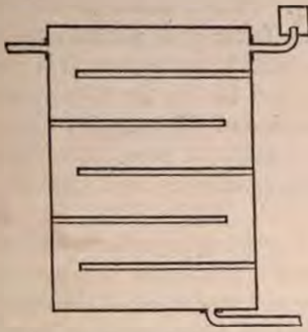

FIG. 31.—PLAN OF CONDENSING CHAMBER.

This chamber, shown in section at Fig. 31, is provided with removable trays over which water flows. To complete the apparatus, there are required a press with steam-heated rollers to complete the compression previously made; moulds of various forms; an air pump to exhaust the chamber; a stove or chamber, having a capacity of about 100 cubic feet, made with tight joints, having a casing for steam or hot air to heat the exterior, while steam or hot-air pipes heat the interior. A large opening permits the placing or removal of the trays, and it is closed quite tight so that a vacuum can be maintained within ; lastly, a still and its condenser.

The pyroxyline is treated as required with solid or liquid solvents. The liquid are to be preferred for the production of transparent and even translucent pyroxyline, for the solution can be filtered and then distilled in a retort to remove the solvent, the pyroxyline being then in a state of paste, which can be moulded and then completely dried. For imitations of ivory and other opaque substances camphor is employed, which is bruised with water, 42 to 50 parts of camphor being added to 100 parts of pyroxyline, both being considered as dry. After a thorough mixture the material is enclosed in strong fabric and placed in a hair bag between the plates of the heated press, where it is pressed for an hour or more. The cakes left in the fabric covers may then be subjected to the action of the hot roller press, and then placed in the vacuum chamber in presence of absorbents, such as chloride of calcium or concentrated sulphuric acid, to remove all moisture.

During the hot pressing superheated steam or air or liquid heated above 212° Fahr. may be employed, the higher temperature being required to effect the solution of pyroxyline in camphor. The thin plates can then be united by heat and pressure, moistening them or not with alcohol, ether, and the like. Into the products may be introduced any resinous or other substance or colouring matter, making paste of uniform colour, or spotted, or marbled. The pyroxyline is rendered less combustible by washing it before compounding in a solution of silicate of soda, and introducing into it phosphate of ammonia or of soda, or borate of lead, or the more fusible fluxes used for painting on porcelain or glass. As pyroxyline is not readily attacked by acids, it may be used as a material for many parts of the apparatus employed for its manufacture.

Proportions in which Cellulose is found. — The following analyses of raw cotton, wheat and barley straw, and of a number of woods, afford illustrations of the extent to which cellulose is associated with other substances in various vegetable products:—

	Water.	Aqueous Extract.	Alcohol-benzene Extract.	Cellulose.	Incrusting substances.
Cotton	7·00	0·50	0·40	91·35	0·87
Barley straw	11·75	9·34	1·99	49·22	27·70
Wheat straw	10·39	8·52	1·58	49·17	30·34
Alder	10·70	2·48	0·87	54·62	31·33
Beech	12·57	2·41	0·41	45·47	39·14
Birch	12·48	2·65	1·14	55·52	28·21
Black Poplar	12·10	2·88	1·37	62·77	20·88
Box	12·90	2·63	0·63	48·14	35·70
Chestnut	12·03	5·41	1·10	52·64	28·82
Ebony	9·40	9·99	2·54	29·99	48·08
Fir	13·87	1·26	0·97	56·99	26·91
Lime	10·10	3·56	3·93	53·09	29·32
Mahogany	12·39	9·91	1·02	49·07	27·61
Oak	13·12	12·20	0·91	39·47	34·30
Scotch Fir	12·87	4·05	1·63	53·27	28·18
Teak	11·05	3·93	3·74	43·12	38·16
Willow	11·66	2·65	1·23	55·72	28·74

CHAPTER XI.

VARIOUS OTHER EXPLOSIVES.

THE Sprengel Explosives—Flameless Explosives—Roburite—Experiments with Roburite and other Explosives—Mr. Hilton's Rules for using Roburite—Bellite—Securite—Trench's Fire-extinguishing Compound—Favier's Explosive—Hellhoffite—Romite—Rack-a-rock—Panclastite—Melinite—Turpin's Shell.

The Sprengel Explosives.—Amongst the variety of explosives which of late years have been brought to the public notice, such excellent results have been attained with one class amongst them—the *Sprengel Explosives*—that it may not be impossible in the near future that the dynamites may find some successful rivals among that class. *Rack-a-rock* may be especially mentioned, as it was this compound which the investigations of the officers of the United States Government induced General Newton to adopt in the great blasting operation at Hell Gate in 1885.

In all the Sprengel explosives the essential principle is the admixture of an oxidising with a combustible agent at the time of, or just before, being required for use, the constituents of the mixture being non-explosive when separate.

Sprengel followed up the idea that an explosion is a sudden combustion, and he submitted a variety of mixtures of oxidising and combustible agents to the violent shock of a detonating cap. These mixtures were made in such proportions, that their mutual oxidation and deoxidation should be theoretically complete.

Among them are the following:—

a. 1 chemical equivalent of nitro-benzene to 5 equivalents of nitric acid.

b. 5 chemical equivalents of picric acid to 13 equivalents of nitric acid.

c. 87 chemical equivalents of nitro-naphthaline to 413 equivalents of nitric acid.

d. Porous cakes or lumps of chlorate of potash exploded with a variety of substances.*

All explosives of this class require a detonator. When nitric acid is one of the ingredients, the greatest care is necessary to avoid its coming into contact with the explosive contained in the detonator.

The Sprengel explosives consist of two ingredients, which when kept separate are harmless, but when mixed form powerful compounds; and the mixing is therefore executed at the mines, generally before their insertion into the bore-holes.

Flameless Explosives. — The terrible significance of accidents in coal mines, resulting from fire-damp explosions, is too well known to require any comment here. According to the *Colliery Guardian* (15th April, 1887), official statistics show that "during 50 years, ending 1885, there have occurred 503 *fatal explosions*, in which about 5000 *miners have lost their lives.* This gives an average of ten such explosions a year, and an average of ten deaths to each explosion."

It is needless to say that these disasters in collieries have drawn the attention of scientists to the importance of producing a compound which should not produce any flame when exploded in the bore-hole in fiery mines. The first step in this direction was the introduction of the so-called "water cartridge," invented by Mr. Settle, of Bolton. In this invention, the explosive charge was disposed in such a manner that it was entirely surrounded by water, and the flame was therefore quenched by this water at the instant of its explosion.†

The economic value of the water cartridge led to further advances, and amongst the substitution for water of solid materials which possess fire-quenching properties, and ulti-

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* See 'Dictionary of Explosives,' by Major J. P. Cundill, R.A.

† See *post*, Chap. XVII., on the 'Use of Explosives in Fiery Mines.'

mately to the invention of a series of so-called *Flameless Explosives*, the properties of which, chemical as well as physical, are discussed in the following pages. The subject is one of great importance, as by the production of a *truly flameless explosive* a great boon would be conferred on the coal-mining fraternity, to whom I would seriously recommend an impartial trial of these new compositions. They should thoroughly experiment with these explosives before pronouncing a judgment *pro* or *contra* any of them, as only by continued practical use in the mines over an extended period can the value of an explosive be determined.

Roburite belongs to the variety of explosives the resolution of which into gases is not accompanied by a flame when detonated under confinement; and it is claimed that, as the resulting explosion gases will not ignite fire-damp or coal dust in coal mines, the name "flameless," therefore, is an appropriate term.

This explosive is the invention of Dr. Carl Roth, a German chemist, and he contends that by his peculiar process of chlorinating and nitrating certain coal-tar products and then mixing them with some inorganic oxygen-yielding substance, he obtains a compound which evolves gases which will instantaneously quench any flame that may be produced by the explosion. In fact, the practical effect is somewhat similar to that produced by Settle's water cartridge, with the distinction that the quenching element is chemically combined with the explosive, whereas in the water cartridge the explosive is surrounded with water.

The chemical compound, as I am informed, consists of chlorinated dinitro-benzol mixed with certain proportions of ammonium nitrate, calculated to oxidise it completely, and in the result Dr. Roth claims to produce a practically flameless detonation.

Dr. Carl Roth gives the chemical equation for the decomposition of roburite as follows:—

$$\underbrace{C_6H_3Cl(NO_2)_2 + 9NH_4NO_3}_{\textit{(Organic.)}\qquad\text{(Inorganic.)}} = 6CO_2 + 19H_2O + 20N + HCl$$

Putting the molecular weights in place of the above symbols—

$$\begin{array}{cl} [202\cdot5 + 720] & \left\{\begin{array}{llll} 264\ + & 342\ + & 280\ + & 36\cdot5 \\ \text{Carbonic} & \text{Water.} & \text{Nitrogen.} & \text{Hydrochloric} \\ \text{Acid.} & & & \text{Acid.} \end{array}\right\} \\ 922\cdot5 & \qquad 922\cdot5 \end{array}$$

Roburite has theoretically, by the dynamometer of Trauzl, nine times the force of gunpowder. The product of its gas volume and calories (units of heat) is given as 1,150,000, that of dynamite being about 950,000.

From what has been said, it will be seen that roburite belongs to the Sprengel type of explosive, being a mixture of two substances, neither of which separately possesses explosive properties; in this case both components are solid, and the resulting mixture has a sandy granular appearance, somewhat resembling the commonest yellow sugar.

As is shown in the following pages, two other explosives, called *Securite* and *Bellite*, possess similar properties to roburite, and do not differ materially as to composition; but as roburite is now being manufactured on a commercial scale in England, and is in actual use by miners, I shall give results of experiments which were conducted with a view to substantiate Dr. Roth's claims.* These were:—

"1. That the two components are perfectly harmless and inert separately, so that they can be stored and transported without any restriction whatever.

"2. That even when mixed or ground up together in an ordinary coffee, cement, or flour mill, the mixture is perfectly safe to handle and use, as neither percussion, friction, nor the application of an ignited or heated body will cause it to explode; this can only be effected by using a detonator charged with fulminate of mercury.

"3. That, when detonated, roburite produces neither spark nor flame, and will not, therefore, ignite fire-damp nor coal dust in mines. Dr. Roth states that this point was decided by

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* For the particulars here given of these experiments, I am indebted to the inventor, Dr. Roth.

the trials of the Imperial German Commission upon Accidents in Mines, and that, in consequence, this explosive is now being introduced into the coal-mining regions of Germany, as affording absolute safety to the men employed.

"4. The amount of noxious gases produced by this explosion is so infinitesimal, that for this reason alone it is superior to other explosives in common use for longitudinal and deep mining work. The report from a mine in Westphalia, with shafts about 1500 ft. deep, states with reference to roburite :—'The men are not inconvenienced by the gases, and experience no difficulty whatever in breathing the moment after a shot has been fired, and they resume their labour at once.'

"5. Roburite is not subject to deterioration through climatic variations of temperature. It should be kept dry, but if it becomes damp, its strength can be safely restored by drying."

The experiments were conducted at Chatham, and the proceedings are thus described :—

"*Safety Tests.*—1. After being ground through a small hand-mill, the substance was struck direct and glancing blows with heavy hammers upon iron plates without exploding.

"2. Flame was then applied to a portion of it by means of a short length of Bickford fuse, but without igniting the mass.

"3. Thrusting a red-hot iron from a portable forge into the roburite caused only slow combustion and crepitation locally, which ceased when the iron was withdrawn. When a quantity was put on the forge fire it merely burnt away like an ordinary combustible.*

"*Test for Strength on Steel Plates.*—The plates were laid flat in shallow trenches, a hollow being left underneath the central portion of each plate; heavy timber balks were stacked around each square trench with the object of showing the comparative dispersive force of each explosive.

"1. 3 lbs. each of dynamite and roburite were placed on the

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* I would not recommend miners to repeat such experiments. It is well known that dynamite will also burn away without exploding, but I know of cases where it exploded when set on fire, especially when in bulk.—M. E.

centre of plates 2 in. thick, some sandy loom being piled loosely on top. The results of detonation were that the dynamite produced a dent in centre of plate 1¾ in. deep; the indentation produced by the roburite was about 1½ in. deep, but the bulge appeared to have a wider area than in the former case.

"2. 5 lbs. each of roburite and gun-cotton were then exploded upon the same plates, with the result that in the former case the plate was smashed into four tolerably equal pieces, while the gun-cotton made a breach through the centre of the plate somewhat resembling that which would be caused by the penetration of a large projectile; the diameter of the hole was roughly 12 in., with five radial fissures almost reaching the edges, the longest 15 in., the plate being at the same time bent into the shape of a pack saddle; this would seem to have been a remarkably tough piece of metal. The timber balks were scattered in all directions.*

"3. 8 lbs. each of dynamite and roburite were then detonated upon plates 3 in. thick. The dynamite caused an indentation 2¼ in. in maximum depth, while the roburite gave a bulge 3 in. deep in the centre, and of a larger area, reaching apparently almost to the corners of the plate.

"4. This series of tests was concluded by exploding 12 lbs. each of roburite and gun-cotton on plates 4 in. thick, rather more loam being heaped on top of each. The roburite caused a wide indentation of 1⅞ in. deep in centre, while the tremendous local force of the gun-cotton was exemplified in a striking manner; in addition to an indentation 3½ in. in greatest depth, a small crack appeared to extend right through the plate, this crack corresponding with one edge of the lowest slab of gun-

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* From experiment No. 2, I conclude that gun-cotton by its more local action would be more adapted for offensive or defensive torpedo charges, as it would blow a hole in the bottom of a ship without destroying it. The ship after sinking could be raised and easily repaired, whereas roburite would most likely twist and disturb the ironwork, making it useless, but as a bursting charge for shells, the dispersive effects of roburite may prove an advantage in attacking large bodies of troops.—M. E.

cotton, the rectangular shape of which could be clearly seen indented on the steel plate, the depth being ¼ in. at the crack and ⅛ in. along the other edges of the slab. There is a circular hole drilled in the slab of wet gun-cotton to receive a small cylindrical disc of dry gun-cotton, as a primer, and the position of this disc was marked by a circular hollow in the steel plate ½ in. deep in centre.

" *Ground Mines.*—10 lbs. each of gun-cotton, blasting gelatine, and roburite were loaded into holes in the bottom of the ditch 4 ft. deep by 8 in. in diameter, filled up with sand, and slightly tamped; the explosion of these charges cast up tremendous fountains of loam and sand, and resulted in the following craters: gun-cotton, 10 ft. 6 in. wide by 1 ft. 8½ in. deep; gelatine, 14 ft. 6 in. wide by 3 ft. 7 in. deep; roburite, 12 ft. 3 in. wide by 2 ft. 9 in. deep. The explosion of the gun-cotton mine appeared to cause great local action, but it will be seen that the area and depth of its crater was considerably less than that caused by the roburite, which again must yield the palm, in this instance, to the blasting gelatine. It is, however, to be remarked that these mines had been placed much too close to one another, so that their craters crossed; this would give whichever charge was the last to explode a certain advantage."

From the published reports* of competitive trials made in the Wharncliffe Silkstone and Monk Bretton Collieries between roburite and other explosives, it will be seen that roburite was found to exhibit all the characteristics of a true high explosive, in respect of the amount of work done in breaking rock and coal. During these experiments it was noticed, also, that the explosion of the charges in the bore-holes produced no visible flame.

To determine the flamelessness of roburite the following series of experiments (we are told) were made:—

" 1. A shot fired on the ground, exposed; this gave no perceptible flame (70 grammes of roburite was the charge in these experiments).

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* *Engineering*, 28th October, 1887.

"2. A shot fired on the ground, bedded in fine coal dust; no flame nor ignition of the coal dust was perceptible.

"3. A shot fired suspended in a case into which gas was conducted, and the atmospheric air allowed to enter so as to form an explosive mixture. The gas was not fired.

"4. A shot fired in a boiler flue 16 ft. by 2 ft. 8 in., placed horizontally, in which was a quantity of fine coal dust kept suspended in the air by the action of a fan. No flame nor ignition of the coal dust took place.

"5. A shot fired as above, except that an explosive mixture of gas and air was flowing into the boiler tube in addition to the coal dust. That this mixture was fire-damp was proved by the introduction of a safety-lamp, the flame of which was elongated, showing what miners call the 'blue cap.' There was no explosion of the gas, or sign of flames.

"6. A shot of roburite fired in the boiler tube without any gas or suspended coal dust. The report was quite as loud as in the preceding case; indeed, to several present it seemed more distinct.

"7. A shot of ½ lb. gunpowder was fired under the same condition as No. 5, *i.e.* in an explosive mixture of gas and air with coal dust. Not only was there an unmistakable explosion of the fire-damp, with very loud report, and a vivid sheet of flame, but the gas flowing into the far end of the boiler tube was ignited and remained burning until turned off."

Several shots were fired in the pits, while the lamps were covered so as to produce complete darkness, but no flame or spark was perceptible, according to the report of the witnesses present.

Mr. James Hilton, in a paper read before the Manchester Geological Society, says that after an experience gained in firing over 3500 roburite charges, he had drawn up the following conclusions and rules for the use of roburite:—

"1. It was reliable on account of the safety with which it could be transported and stored.

"2. That it took a very strong detonator to explode it.

"3. It was practically flameless under pressure, the gases evoked in its combustion being of such a character as to quash any initial flame there might be.

"4. In fiery mines, it should be treated so as to confine the gases, and give them a chance of action on the initial flame at the moment of action, the quenching element being chlorine.

"5. With regard to the gases evolved by the decomposition of roburite, it appears from the formula of the inventor that there are no noxious nitrous fumes caused by its explosion.

"6. The drill hole should only be a trifle larger than the diameter of a cartridge, and is more suitable when machine-drilled.

"7. Open one end of the cartridge, bore a hole down the centre of it (with a wooden peg), then insert the detonator well into the middle of the cartridge, and next tie the covering of the cartridge point to the fuse.

"8. In tamping be careful to use dry material, and to ram the hole very lightly for the first three or four inches, so as not to displace the detonator or compress the roburite. Afterwards tamp finally for not less than a foot, with clay or damped borings from the drill hole. This rule is most important, as the safety of the explosive depends on the tamping.

"9. Fire the detonator with an electric fuse where fire-damp is given off or coal dust is present.

"10. Store roburite in a dry place, and if the hole is wet fire the charge as quickly as possible after it has been placed in the hole.

"11. If the charge misses fire disconnect the cable from the battery, and wait ten minutes before going to it, for although there has not been a single case of hanging fire with me in over 3500 shots, yet I have heard of an accident happening through a shot hanging fire for a few minutes. It is supposed that the paper at the end of the electric fuse inserted in the detonator smouldered for a short time and fired the fulminate of mercury."

After giving the details of a large number of experiments, Mr. Hilton observed that in the number of roburite shots he had mentioned either sparks or a flash had been seen, on an average, once in a hundred times, but in none of these, in his opinion, would an inflammable mixture have been ignited, although the margin between danger and safety would have been very near.

Bellite.—This explosive has been invented by Mr. Carl Lamm, who introduced its manufacture in Stockholm. It is essentially a mixture of nitrate of ammonia and di- or tri-nitro-benzol. These substances are mixed together at a temperature of 176° to 194° Fahr., which melts the latter, causing it to thoroughly cover over all the particles of the nitrate ammonia, and protecting this substance from atmospheric influence; and a compound is formed of which each molecule is explosive.

In its granulated state, and in cartridges, its sp. gr. is 1 to 1·2, and in this condition it is said that it can be readily exploded by an ordinary fulminating cap even under confinement. When compressed, however, into solid cakes, it needs more powerful detonators and also strong confinement. It evaporates at about 300° Fahr., and at a higher temperature it is stated that it will not explode. Unlike nitro-glycerine, dynamite, &c., which detonate violently when suddenly heated to a like temperature, bellite is said to take fire only and to burn as fat. It is also stated that bellite is non-sensitive against blows, friction, and vibration, and that it possesses great chemical stability, permitting long storage and transportation to distant countries.

It has been placed on the list of licensed explosives in England, and steps have been taken for its manufacture here.

Securite, like bellite and roburite, consists of a mixture of meta-dinitro-benzole with nitrate of ammonium or nitrate of potash. The proportions are about 26 parts of the former to 74 of the latter. It is a yellow powder, with the odour of nitro-benzole. Other varieties contain trinitro-benzole or di- or trinitro-naphthaline. The following equations are given as representing the various compositions and their products of combustion, and claim to show that it is a perfectly safe explosive to use in the presence of fire-damp and coal dust:

$$C_6H_4.2\,NO_2 + 10\,(NH_4.NO_3) = 6\,CO_2 + 22\,H_2O + N_{22}$$
$$2\,(C_6H_4.3\,NO_2) + 15\,(NH_4.NO_3) = 12\,CO_2 + 33\,H_2O + N_{36}$$
$$C_{10}H_6.2\,NO_2 + 19\,(NH_4.NO_3) = 10\,CO_2 + 41\,H_2O + N_{40}$$
$$2\,(C_{10}H_5.3\,NO_2) + 33\,(NH_4.NO_3) = 20\,CO_2 + 71\,H_2O + N_{72}.$$

As is shown by the preceding chemical formulas the composition of both securite and bellite, does not vary much from roburite, although securite substitutes as an oxidising salt the nitrate of potash for the nitrate of ammonia.

Experiments have been extensively reported upon both abroad and in England by various authorities, and the results may be summarised as follows:—

Securite and bellite do not seem to explode by friction, pressure, a blow, fire, or electricity, but detonate under the influence of a powerful detonator.

It is claimed that the explosion gases are innocuous, and that the explosion is not accompanied by any amount of flame or gases. That they belong to the flameless variety has been shown by experiments, where these explosives were exploded in a gaseous mixture of a hydrocarbon and air, inside an iron tank; such a mixture is highly explosive, but securite and bellite explosions did not fire it, whereas gunpowder did.

Their action in coal and stone is more in the nature of rending than of pulverising.

Unlike nitro-glycerine preparations, they do not freeze in cold weather.

Cartridges of these explosives, when thrown into a fire, simply fizzed away without exploding.

Heavy weights, when dropped from a certain height on to the cartridges of these explosives, did not explode them.

That they may possibly be applied for military purposes is shown by the fact that cannon balls can be propelled with ese explosives from guns, and a 32 lb. ball was sent flying ugh the air for a distance of 95 yards when fired with

¼ oz. of bellite, whereas ½ oz. of gunpowder sent it only to a distance of 40 yards; but it remains for future experiments to demonstrate if larger charges of these explosives could be used in artillery, to send balls to a distance of several miles, such as actual military operations would require.

Trench's Fire-extinguishing Compound, manufactured by the Cotton Powder Company, is the invention of Mr. G. Trench, the manager of the company at Faversham. The object of the invention is to surround the cartridges of tonite, when used in coal mines, with a composition which will extinguish the flame of the shot. It consists of sawdust impregnated with certain chemical substances, and to an inexperienced eye it has the appearance of dirty salt. If a charge of tonite, or of dynamite or gelatine-dynamite, is packed inside a few ounces of this mixture, and then fired, not the least trace of flame can be observed, and experiments appear to show that there is no flame at all. The following report* of experiments conducted in the presence of several scientific gentlemen and practical members of the mining community has been published:—

"A large wrought-iron tank, of 45 cubic feet capacity, had been sunk level with the ground in the middle of the yard; to this tank the gas had been laid on, for a purpose that will be explained later on. The charges were fired by means of electricity, a small dynamo-firing machine being placed from thirty to forty yards away from the 'mine.' Operations were commenced by the top of the tank being covered over and plastered down in order to make it air-tight; then a sufficient quantity of coal gas was placed in it to make it highly inflammable and explosive, the quantity being ascertained by a meter which had been fixed specially for the purpose. Whilst the gas was being injected, the cartridge was prepared. The first experiment was to try whether a small charge of tonite—fired without the patent extinguisher—would ignite the gas. The gas having been turned on, a miner's lamp was

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* From the *Faversham News*, 22nd October, 1887.

placed in the 'tank,' but this was extinguished before the full quantity of gas had gone through the meter. However, the gas being in, the charge (1¼ oz. tonite) was placed in the 'mine,' the detonator was connected by means of long wires to the dynamo machine, and the word was given to 'fire.' With a tremendous report, and a flash of fire, the covering of the mine flew in all directions, clearly showing that the gas had been ignited and added considerably to the noise of the report and the force of the explosion. The next cartridge (a similar charge) was prepared with the patent compound. First of all a brown paper case of about two inches diameter was taken, and one of the tonite cartridges was placed in the centre of it, the intervening space between the charge and the case being packed with the 'Fire-extinguishing Compound.' The mine having had another supply of gas injected, the protected cartridge was placed inside and fired. The result was astonishing, the explosion not being nearly so loud, whilst there was not the least flash of fire. 'Protected' and 'unprotected' charges were fired at intervals, gas being turned into the tank on each occasion. Two ¾ oz. charges of tonite were fired without the compound, and on each occasion the gas was exploded, and the jet at the end of the supply pipe was, upon examination, found to be alight. Charges varying from 1 oz. to 6 oz. of tonite were fired with the compound, and on each occasion the report was trifling, whilst no flash could be seen."

In actual mining the paper case can be dispensed with, the charge being placed in the bore-hole and tamped down with the fire-extinguishing compound around it, but to ensure the explosive being entirely surrounded with compound the paper bag should be used.

The accompanying illustration shows the manner of placing the tonite cartridge in the paper bag, and surrounding it with the fire-extinguishing compound *a*, *a*. The attachment of fuze and detonator is also shown, as well as the wooden *rammers*.

Favier's Explosive.—This compound is prepared by coating nitrates, such as nitrate of ammonia, with a molten hydro-carbon, like paraffin, and then compressing the substance into a cartridge.

With this object in view, during manufacture the moulds in which the compression is effected are heated by means of a circulation of hot water or steam at the melting point of the hydro-carbons, or better, the material is brought to this temperature in a mixer; under the double influence of the pressure and heat the material agglomerates itself, the hydrocarbon covering the molecules of the nitrate with a protective coating which may exude slightly and so form externally a sort of protective varnish to the mass, which may be further augmented by plunging the material on its coming from the mould into a melted waterproof mixture.

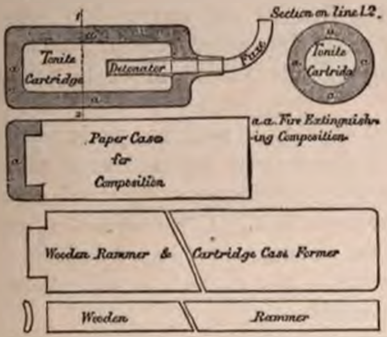

FIG. 32.—APPLICATION TO CARTRIDGES OF TRENCH'S FIRE-EXTINGUISHING COMPOUND.

For the manufacture of more feeble explosives, nitrate of soda is employed, either alone or mixed with nitrate of ammonia or with any other compound capable of readily giving off the hydrogen which it contains. Before the compression of these two compounded substances sulphur may be added to them, which will lower the temperature of their transformation into gas.

The mixture of nitrate of ammonia and of the hydro-carbon with or without sulphur, worked at the minimum density of 1·6, possesses a very great stability and does not explode, as do the nitrous bodies, under the influence of an ordinary fulminating capsule, and consequently recourse is had to an intermediate nitrous body, the points of contact whereof with this improved compound are multiplied as much as possible.

For this purpose a cylindric opening is formed in the centre of the moulded cartridge along its longitudinal axis, these cartridges of course being made of nitrate of ammonia coated with the molten hydro-carbon; and in the said opening is placed a nitrated explosive body intended to communicate the initial detonation to the surrounding compound, thus increasing the initial detonation produced by the discharge of the fulminating capsule placed in contact with the nitro-compound.

In the central opening, gun-cotton, picric acid, the chlorates of ammonia or potash, may be used as a priming, the last two substances being previously incorporated or covered by an easily fusible hydro-carbon. These detonating compounds are moulded in form corresponding to the hole in the cartridge, and can be inserted either at the time when the explosive is to be used or previously.

By employing a quantity of gun-cotton or chlorate not exceeding one-tenth of the weight of the moulded compound to be detonated, the explosion will be positively ensured.

By using the hollow cartridge, Favier is enabled to utilise certain explosive acid mixtures of the Sprengel type, which are produced by dissolving certain hydro-carbons, phenols, natural alcohols, in nitric acid or in nitric peroxide, or nitrates, sulphates, carbonates, &c.

Several of these mixtures, in which the nitrated elements and hydro-carbons are simply in juxtaposition, will produce explosives, which according to theory are equally powerful as compound with nitro-glycerine preparations, for they can be made in required proportions for obtaining a complete combustion of their elements, and moreover do not need to give over during the detonation the heat absorbed by the fixing of the nitrous elements on the glycerine.

These explosives are brought to a state of paste by absorption in infusorial earth, or are placed in the central opening of the cylinder of the primary compound, the ends of which are covered by a plug of the same material, or by an inert body such as paraffin. They are exploded by means of strong fulminating caps.

Hellhoffite is a mixture of nitro-petroleum or nitro-tar oils with nitric acid. One form of it—proposed by Gruson—has been tried in shells, and consists of meta-dinitro-benzole (C_6H_4, 2 NO_2) and nitric acid. The two substances are placed in separate receptacles in the shells, and are automatically mixed during the flight or on the impact of the shell, as the case may be.

Romite is a Swedish explosive, consisting of a mixture of nitrate of ammonia with naphthaline or nitro-naphthaline. When required for use, this is to be mixed with chlorate of potash. The nitrate of ammonia is also employed when coated with a jacket of molten paraffin and naphthaline; when so prepared in admixture of chlorate of potash it forms a compound equal in strength to ordinary dynamite. ✓

This explosive is used successfully in Sweden. It does not seem to explode accidentally, and may have a future before it. Experience has shown that a chemical action is likely to set up between the nitrate of ammonium and the chlorate of potash, which renders spontaneous combustion possible, but this tendency the persons interested in the preparation of romite are endeavouring (I am informed) to overcome.

Rack-a-rock consists of compressed cartridges of chlorate of potash impregnated before use with dead oils or other liquid hydro-carbons, or with nitro-benzole; or a mixture of dead oil with its own volume of bisulphide of carbon; or a mixture like the last with the addition of 3 per cent. of sulphur.

The chlorate of potash cartridges are enclosed in small bags of cotton or other cloth, of suitable size and shape, and dipped into the liquid. The mixture of dead oil and bisulphide of carbon is used by preference, the object of the bisulphide of carbon being to prevent too large a proportion of dead oil from being taken up by the chlorate. The bisulphide afterwards evaporates out.

Nitro-benzole is also used as a dipping liquid, or as an ingredient thereof in combination with picric acid.

In practice, the cartridges are suspended in a wire basket from a spring balance and dipped into a pail containing the fluid. The completion of the absorption of the proper amount of fluid is shown by the spring balance. The proportions given are three to four and one-sixth parts solid to one part liquid ingredient.

If the cartridges be kept, they appear to tend to increased sensibility to friction or percussion.

Panclastite is a name given to various mixtures proposed by M. Eugène Turpin, of Paris.

In some of these mixtures he proposes to mix liquid nitrogen tetroxide or nitric peroxide (N_2O_4)[1] with bisulphide of carbon, benzole, petroleum, ether, mineral volatile oils, or other liquid or solid hydro-carbons. He recommends especially a mixture of $2\ CS_2 + 3\ N_2O_4$; but the use of two such ingredients, both giving off highly deleterious vapours, is a very serious objection to a mixture to be used in a mine or other confined space, and the vapour given off by the liquid N_2O_4 is especially dangerous. He also proposes a mixture of about eighty parts chlorate of potash to twenty parts coal tar, with the addition, if necessary, of some porous absorbent for the liquid tar. Two of his powders are as follows:—

	No. 1.	No. 2.
Chlorate of potash .	80 per cent. . .	40 per cent.
Coal tar	14 to 16 ,, ,, . .	15 ,, ,,
Wood charcoal . .	4 ,, 6 ,, ,, . .	40 ,, ,,
Nitrate of potash . .	— . .	40 ,, ,,

[illegible] granulated like ordinary powder, or [illegible] compressed cartridges.

Melinite—an explosive which is simply an adaptation of picric acid—is also the invention of M. Turpin. Picric acid by itself had always been considered as an imperfect body, not capable of explosion without an admixture of an oxidising substance, like chlorates, nitrates, chromates, nitric acid, &c. But in practice these mixtures proved too dangerous, as the picric acid displaced the nitric and chloric acids from their salts, and thus caused spontaneous explosion; and such compounds have caused some terrible disasters.

Turpin discovered that, contrary to all the theories adopted, picric acid alone—that is to say, neither mixed nor combined with any active substance and such as it is found in commerce—is one of the most powerful and valuable explosives that can be conceived. Its explosive force is greater than that of compressed gun-cotton and the different forms of dynamite. Its insensibility to shock, as well as its stability, is also very remarkable. Turpin also demonstrated that the maximum force of explosives of this kind, contrary to what has been believed, does not coincide with the chemical formulæ, which correspond to complete combustion, but on the contrary with the combustion which yields carbonic oxide. On this novel theory, therefore, the maximum of power may be obtained with nothing near the maximum sensibility, which admits of obtaining results hitherto unlooked for. It is generally admitted that the power of explosives is proportionate to the heat disengaged, which has always led chemists to employ the oxidising agent, and preferably in excess, in order to obtain complete combustion. This, however, was a grave mistake, as the oxygen necessary to form carbonic acid could produce a double volume of carbonic oxide, which would produce a much more considerable amount of work, and which is far from being compensated by the increase in value of the temperature which is produced in the case of the formation of carbonic acid. As regards the carbonic oxide this need not be considered, as its conversion into carbonic acid takes place immediately it is projected into the air, by the action of the flame of the explosion, and at the expense of the oxygen of the air. Turpin found that when picric acid alone, without any admixture, is fired by means of an initial detonator of sufficient power it is capable of producing the most violent bursting effects, for which reason it is proposed to apply it for industrial and military uses, by the novel means and processes hereinafter described.

This application is the more important, as hitherto an explosive for military uses possessing the following properties found in picric acid alone has never been obtained, viz.: 1. Absolute chemical stability, that is to say, non-susceptibility of spontaneous decomposition or of elementary change. 2. Absolute physical stability, that is to say, non-susceptibility of congelation, exsudation, liquefaction or evaporation. 3. Absolute insensibility to the most extreme variations of atmospheric temperature. 4. Capability of being preserved for an indefinite period. 5. Perfectly non-hygrometric. 6. Perfect security in manufacturing, manipulation, and transport. 7. Little or no capability of ignition in the open air. 8. Greater power of dispersing earth than either gun-cotton or dynamite. 9. Shattering properties equal, if not superior, to those possessed by other violent explosives. 10. Insensibility, or at least inexplosibility, on the ball striking. 11. Insensibility (when used in shells) to the shock of the discharge of the cannon.

The insensibility of picric acid by itself is due to the excess of carbon which it contains, and for this reason it is absolutely necessary to avoid the admixture of any oxidising substance, as it considerably increases its sensitiveness, as well as greatly reduces its power. Picric acid, unmixed, attains its maximum sensitiveness to priming, this property being very slight when it is in the form of fine powder; although but slightly sensitive to shock, its sensitiveness may be still further reduced by different means, which admirably adapt it for, and, in fact, are indispensable to, its use if it is desired to obtain satisfactory results.

These processes consist (1) in compressing the picric acid, *in order to* increase its density, and, at same time, lessen its sensitiveness, contrary to what is the case with gun-cotton, it being well known that gun-cotton in a flocculent form is not exploded by a priming, whereas it explodes readily when compressed. (2) By agglomerating it (and at the same time moulding it to various forms) with an aqueous solution of gum arabic, or some fatty body, such as heavy oils, fats, etc., which have the property of rendering picric acid insoluble, and then allowing it to dry if necessary. (3) Collodion jelly diluted in the proportion of from three to five per cent. in a mixture of alcohol and ordinary ether, may also be used to agglomerate the picric acid to lessen its sensitiveness, and adapt it for being moulded into any form. Blocks thus obtained will explode in a closed chamber, with primings of from one to three grams of fulminate. The maximum of insensibility is obtained when in the cast state, which is one of the best modes of employment. In this case it will resist, in the open air, the explosion of a priming composed of three grams of fulminate inserted in the cast mass, but it explodes perfectly in a closed chamber, such as a shell, for example, as will be hereinafter explained. Cast picric acid behaves much like wet gun-cotton, that is to say, it may be exploded even under water with a priming of picric acid in dry powder, which is itself primed with 1·5 grams of fulminate. Very powerful explosions may, in this manner, be obtained. Cast picric acid perfectly resists the shock produced by the firing of a cannon, when contained in a projectile, having an initial velocity of six hundred metres, and produces destructive effects of a kind hitherto unknown.

The following is the process of casting the picric acid: The acid is fused in a vessel provided with a false bottom heated to × 130° to 145° C. by a current of steam under pressure, or simply by the circulation of a liquid heated to the desired temperature, such as oil, chloride of zinc, glycerine, etc. The melted picric acid is run into moulds of a form corresponding to that of the blocks required, or it may be run into the projectiles themselves, which should be heated to a constant temperature of about 100° in order to prevent too rapid solidification. The importance of the application of this method is considerable. It has been observed that in large projectiles at a high velocity, ordinary powder, if in small grains, sometimes ignites through the friction which results from its settling down, in consequence of the initial shock, whereas if it is in the form of compressed blocks it resists ignition. For this reason, it is preferred to employ for hollow projectiles picric acid, in compressed powder, agglomerated after pressure, or preferably cast, it thus attaining a density of 1·6 to 1·7. This latter mode of use is also more convenient, as it enables the explosive to be cast in receptacles of any form having small orifices, such as shells, torpedoes, tubes, moulds, etc. When required for producing explosions in the open air, for blowing up rails, walls, etc., for military purposes, it is preferable to employ the picric acid in dry powder. In this form it is firmly packed into the cartridge case of tin, copper, or pasteboard, and a priming tube, inserted well into the material, is used, as in the case of gun-cotton or dynamite.

The priming of the picric acid may be effected by the three following means:—(*a*) By the direct employment of a priming of 1·5 grams of fulminate of mercury, which answers well for picric acid in dry powder. (*b*) By employing an intermediate priming of picric acid in powder, primed by the fulminate, which is very suitable when using cast or agglomerated picric acid. (*c*) By dispensing with the fulminate, and employing a sufficiently large charge of ordinary quick-burning powder enclosed in a strong tube, and made to burst inside the charge of picric acid. This last method is of especial importance in connection with artillery.

Turpin's Shell.—Fig. 33 illustrates the invention as applied to the charging of shells, with cast (fused) or powdered picric acid, and with or without a priming of fulminate. The drawing represents a longitudinal vertical section of the shell. A is the body, and B the plug, containing the priming, in the chamber D of which plug may be placed a charge of quick-burning powder, or picric acid in powder. In this latter case, a priming containing from 0·8 to 1 gram of fulminate should be attached to the fuze C. E, copper ring surrounding the base of the shell. The chamber D is coned, and also the core which is used to form a cavity for its reception in the fused or cast acid, to enable said core to be easily drawn out. It will thus be seen that in order to produce the detonating explosion of the picric acid, or, on the same conditions, that of the compressed gun-cotton or dynamite without the use of fulminate, a cavity is moulded in the charge of compressed, agglomerated, or cast picric acid, to receive the screw plug, which terminates at its inner end, in a very strong, but brittle, chamber of cast steel, or iron, which is filled with very violent gunpowder, or, preferably, with 25 grams of a powder composed of chlorate of potash, tar, and charcoal. The plug is closed by means of the fuze. It will thus be seen that a strong priming of gunpowder is used instead of a priming of fulminate, the only fulminate employed being that contained in the artillery fuze. If it is desired to obtain, either in mines, or elsewhere, an explosion without detonation of the picric acid, a small charge of powder should be employed, either wrapped in paper or contained in a waterproof bag, to be ignited by the miner's fuze, the latter having no action upon the picric acid when unenclosed. Under these conditions the picric acid may be employed in mining and excavating generally in the same manner as dynamite and gun-cotton. If the mine is dry, it is sufficient to introduce the picric acid into the hole, either in powder, or in small crystals, or agglomerated, or cast, and to prime it in the ordinary way.

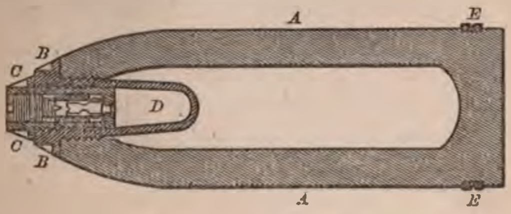

FIG. 33.—TURPIN'S SHELL.

If the mine is wet, or under water, the picric acid must be enclosed in a waterproof envelope of metal, indiarubber, cloth, gummed taffetas, waterproof paper, etc., and primed with a strong priming of dry picric acid in powder which is itself primed, by means of a fulminate. The picric acid is almost completely insoluble in cold water, and detonates freely with a priming of 1·5 grams, if it is moistened with three per cent. of water.

CHAPTER XII.

DETERMINATION OF THE RELATIVE STRENGTH OF EXPLOSIVES.

ELEMENTS of Comparison of Explosives—Methods of Comparison—Experiments of Captain Nobel, Sir F. Abel, MM. Roux and Sarrau, and M. Berthelot—Nobel's Ballistic Test—Calculating the Effect of Dynamite—Iron Plate Test—Pressure Gauge—Foot-pounds Machine—Quinan's Diagram for Measurement of Pressure—Initial Detonation.

THE most vital question which concerns explosives is the evolution, or rather concentration, of their power, absolute and relative. This is a subject to which serious attention has long been given, without leading as yet to satisfactory results.

It is not only from a theoretical point of view that such knowledge is of importance. The manufacturers of explosives are frequently themselves unable to estimate the relative value of other explosives and their own. The pressure gauges devised give only an approximate idea of their relative power. The strength of a dynamite, or its explosive effect, is made up of three factors. It may be considered as equal to the product of the three :—

1. The amount of the gases formed (that is, their volume reduced to a standard temperature).

2. The temperature of the gases.

3. The reciprocal of the time consumed during their evolution.

In practice, be it in mining or quarrying operations, it is really difficult to make comparative tests. Rock which appears to the eye uniform and quite alike, in blasting often brings to light veins, shakes, or fissures which render a comparison of work done in two contiguous portions impossible—in fact, there is no such thing in reality as to make two bore-holes of equal depth and diameter, where conditions of the material to be blasted are identical.

Methods of Comparison of Explosives.—Explosive power may be estimated in two ways, viz. indirectly by theoretical induction, and directly by measuring the maximal tension of the gas at the moment of explosion, or the mechanical work which it is capable of performing, or what means the same, that at the moment of the dissolution of the solid into gases a certain amount of mechanical work is being done by the pressure of the gases evolved and the heat generated. For gunpowder both methods have been applied, without showing much discrepancy in the final result.

Captain Nobel's and *Sir Frederick Abel's* experiments show that the maximal pressure exercised by gunpowder, when the density of the products of explosion is equal to 100, or, in other words, when 1 kilo. of exploded powder occupies the volume of 1 litre, is equal to 6400 atmospheres, or about 42 tons per square inch; that its explosion produces about 705 units of heat, which, multiplied by its mechanical equivalent, represent a theoretic work of 486 foot-tons per lb. of powder.

But highly satisfactory as are those figures, derived from actual measurements, they give no clue to find the absolute or relative power of gun-cotton, nitro-glycerine, and other violent fulminates of modern application. These have been considered too powerful and too quick of explosion for even the strongest steel receptacle to resist their action, and hence, as far as we know, no attempt has hitherto been made to measure their explosive pressure by an instrument similar to those employed by Captain Nobel and others to estimate the tension produced by exploding gunpowder.

By aid of repeated calorimetric tests made at the Depôt Central des Poudres, Paris, *MM. Roux and Sarrau* have sought to determine how much heat the explosion, or rather detonation, of various fulminates produces. They have thus found for

Nitro-glycerine	1784 units of heat
Gun-cotton	1123 ,, ,,
Picrate of potash	840 ,, ,,

which, multiplied by the mechanical equivalent per unit, gives

778 metre-tons per kilo. of nitro-glycerine,
489 ,, ,, ,, gun-cotton,
366 ,, ,, ,, picrate of potash,

as against

378 ,, ,, ,, for the best sporting powder,
and 267 ,, ,, ,, ,, ,, ordinary mining powder,

which is of a very inferior quality.

Comparing those figures with the heat produced by the combustion of gunpowder, as found by Sir Frederick Abel (704 units), and taking it as 1·00, the mechanical power which

Nitro-glycerine is capable of performing would rank as .	2·53
Gun-cotton ,, ,, ,, ,, ,, .	1·59
Picrate of potash ,, ,, ,, ,, ,, .	1·19

Berthelot, following a different method, purely theoretical, arrives at much lower figures for the heat produced by the combustion of the same substances, and consequently also for the amount of work it represents. He admits that at the very high temperature, which is a very general feature of explosive combustion, no complex chemical combination can exist, and that only elementary compounds, such as water vapour, carbonic oxide, and carbonic acid will be formed; so that when the chemical composition of such explosive substances is known, which are entirely converted into gas, it is easy to determine, without recourse to experiments, the nature of the gaseous products formed at the moment of their explosion. Hence, for instance, nitrate of ammonium, of which the formula is $NH_4 NO_3$, would split up into

$$N_2 + O_2 + (H_2 O)_2.$$

Starting from this point of view, the correctness of which certainly does not appear to admit of the slightest doubt, Berthelot computes, from well-known tables, the heat produced by the formation of the gaseous products from their elements. He further eliminates the units of caloric developed in the formation of the explosive substance to be dealt with from its elements, and takes it for granted, of course, that as much heat must be absorbed in disuniting the chemical tie as was freed in forming it. The heat lost in that operation he deducts from the sum of heat produced by the reunion of the disconnected elements, the balance representing the heat really developed by the explosive combustion. Thus, for each 227 grams of nitro-glycerine, which the explosion transforms entirely into carbonic acid, water, nitrogen, and oxygen, Berthelot calculates the heat produced by the formation of the carbonic acid and water from the elements of 430,500 units, and the heat produced by the formation of the nitro-glycerine itself from its prime elements at 130,500 units, which, deducted from the total of 430,500, leaves 300,000 units of caloric freed, or 1320 units per gram of nitro-glycerine exploded.

Nobel's Ballistic Test.—Various devices have been employed for testing the power of explosives, and to measure their relative strength, and the first in use was that adopted by Nobel. He made use for several years of a method based on measurement of the ballistic power of explosives; and though certainly open to some objections, it has the advantage of being extremely handy and sufficiently accurate for the object in view.

A mortar test is indeed more reliable for comparing detonating explosions than for slower compounds; for in the latter case, the projectile may have left the mortar before the combustion is completed, while, in the case of fulminates, their explosive conversion is so rapid that in all probability it is completed before the projectile has begun to move at all, thus acting upon it with the whole force of its initial tension. This is further confirmed by the fact, that the bore of the mortar can be made far shorter than for testing gunpowder, without any considerable falling off of the range of projection. The conclusions which he drew from a series of experiments were that if the ballistic power of detonating

Nitro-glycerine is expressed by		100·0
Compressed gun-cotton, weight for weight, ranks as		71·0
Dynamite of 28% guhr and 75% nitro-glycerine	,,	72·0
Ammonia powder	,,	83·0
Gunpowder mixed with 20% nitro-glycerine	,,	50·0
Gun-cotton ,, ,, its own weight of nitro-glycerine	,,	83·0
Curtis and Harvey's strongest blasting powder detonated with a cap	,,	28·0
Fulminate of mercury	,,	30·0
Lithofracteur of the strongest kind	,,	50·5

In this estimate no deduction has been made for the power exercised by the fulminate of the detonator caps, it being the same for all preparations except gun-cotton, for which 0·16 additional weight of fulminate was used.

Interesting as it may be to compare the relative power of explosive substances, weight for weight, the power which they are capable of exercising, bulk for bulk, is of far greater importance in their application to blasting.

It is easily computed when their specific gravity is known, which has been found

For nitro-glycerine	1·60
,, gun-cotton	1·00
,, dynamite No. 1	1·65
,, ammonia powder	1·55
,, gunpowder	1·00
,, lithofracteur	1·20
,, dynamite No. 2	1·20

When their power is compared, bulk for bulk, the various explosives range as follows:—

Nitro-glycerine	100·0
Ammonia powder	80·0
Dynamite No. 1	74·0
Lithofracteur	53·0
Gun-cotton	60·0
Curtis and Harvey's blasting powder fired by detonator	17·5

Calculating the Effect of Dynamite.—To calculate the pressure developed by the explosion of a charge of dynamite in a bore-hole, let us suppose a bore-hole three centimètres in diameter, charged with one kilogram of dynamite No. 1, containing 75 per cent. of nitro-glycerine.

The pressure in kilograms developed in the bottom of the bore-hole by the explosion gases is determined according to the formula, Vieille and Sarrau :—

$$P = \frac{V_0 \left(1 + \frac{Q}{273 . c.}\right)}{V - v.}$$

in which the letters have the following meaning :—

V_0 the volume, reduced to 0° and a pressure of 760 mm. of the gases produced by a unity of weight of the explosive.

Q the number of calorics disengaged by the explosion of a unity of weight of the explosive.

c the specific heat, at constant volume of the gases.

V the capacity in cubic centimètres of the unity of weight of the explosive.

v the volume occupied by the inert materials of the explosive.

The volume of gases produced by 1 kilo. of nitro-glycerine at 0° and under a pressure of 760 mm., is, according to the experiments of Vieille and Sarrau, 467 litres.

We can therefore take for V_0 :—

$$V_0 = 0{\cdot}75 \times 467$$

equal to

$$V_0 = 350.$$

According to Bunsen and Schiskoff, 1 kilo. of dynamite No. 1 disengages 1290 calorics.

The specific heat c is 0·220 according to Sarrau's calculations.

At last, the density of the dynamite being equal to 1·500, we deduct therefrom :

$$V = \frac{1}{1{\cdot}500} = 0{\cdot}666.$$

If we estimate at 0·100 the volume of the Kieselguhr, we find from the preceding formula that the following values will represent the letters:—

$$P = \frac{350\left(1 + \frac{1290}{273 \times 0 \cdot 220}\right)}{0 \cdot 666 - 0 \cdot 100} = 13{,}900 \text{ atmospheres.}$$

To transfer this quantity into kilograms pressure per square centimètre, it is only necessary to multiply the same by the weight of a column of quicksilver $0^{m \cdot} 760$ high and 1 centimètre square section, which is equal to augmenting it by $\frac{1}{30}$.

$$Pk = Pa\left(1 + \frac{1}{30}\right) = 14{,}317 \text{ kilograms.}$$

In applying the formula to the explosion of gun-cotton, and taking:

$Q = 1075$ (Berthelot)
$C = 0 \cdot 2314$
$V = \frac{1}{1 \cdot 50}$ (absolute density 1·50)
$V_0 = 671$ litres (Vieille and Sarrau)
$v = O$

we find:

$P'a = 18{,}135$ atmospheres
$P'k = 18{,}740$ kilograms.

The explosion of 1 kilogram pure nitro-glycerine gives:

$P''a = 18{,}533$ atmospheres
$P''k = 19{,}151$ kilograms.

The Iron Plate Test consists in estimating the strength of an explosive by its effect in smashing an iron plate of standard thickness and tenacity, when exploded in certain charges on its surface. This test is very delusive, though of value in determining certain other important qualities. *Sir Frederick Abel* has shown that weaker explosives sometimes show better results by these tests than stronger ones; in fact the experiment is rather a test of the completeness of detonation, and of the rapidity of explosion, than of the force which becomes available in rending rock.

The Pressure Gauge is mostly adopted by manufacturers to estimate the force of their explosives. As shown in Fig. 34, it consists of a heavy block of wood A, upon which is bolted a cast-iron block or base B, B, B. In this base are inserted four wrought-iron guides, or standards C, C, set around the circumference of a 4-in. circle. The lead plug D rests upon a steel plate (not apparent in the drawing), which is let into the iron block flush with its upper surface. A ring E holds the guides C in place at the top, passing through the ring, which is held down by nuts F.

FIG. 34.—PRESSURE GAUGE.

FIG. 35.—PISTON OF PRESSURE GAUGE.

FIG. 36.—SHOT OF PRESSURE GAUGE.

The piston H (also Fig. 35) which is the piece resting on the plug of lead, is a cylinder of tempered steel, 4 in. in diameter and 5 in. in length. It is turned away at the sides to lighten it as much as possible. It moves freely between the guides. In the top is a parabolic-shaped cavity to hold the charge of explosive N (Fig. 35). The weight of the piston is 12¼ lbs.

The shot I (also Fig. 36), made of tempered steel, is 4 inches in diameter, and 10 inches in length, weighing 34½ lbs. It is bored through its axis to receive a capped fuze.

To put the instrument in operation a plug of lead is placed upon the steel plate within the guides. The piston is put down gently upon it, and the charge of explosive placed in the cavity N. The shot is next lowered gently upon the piston, and the capped fuze pushed down through the hole in the shot. The fuze being lighted, when the fire reaches the cap the charge is exploded, throwing out the shot and compressing the lead plug. The accuracy of the test is based upon the assumption that the lead plugs shall be of uniform density and homogeneous structure.

The form of plug used is a cylinder, an inch in diameter and an inch in length (Fig. 37).

The lead cylinders used for these experiments are cut out from lead bars, which are manufactured from large masses of metal melted at a high temperature; it is dense and uniform, and can be obtained in lengths of 50 feet. These plugs are more uniform than those cast separately in moulds from small masses of metal.


FIG. 37.—LEAD PLUG.

In making these tests it must be considered that the lead plug, while being compressed by the explosion in the pressure gauge, the density of the plug as well as the lead surface opposed to the piston continually increases. It is self-evident from this that the amount of compression shown by the plug is not a direct measure of the strength of the explosive. For illustration: if one explosive exploded in the pressure gauge, compresses a plug $\frac{250}{1000}$ of an inch, and another explosive compresses a plug $\frac{500}{1000}$ of an inch, the latter explosive would be twice as strong as the former if the compressions were direct measures of relative strengths. But in fact the latter explosive is more than twice as strong. The problem was, how much. The strength of the explosive is proportional to the *work* performed in reducing the height of the lead plug. To get an expression for the work, it was only necessary to find the number of foot-pounds required to produce the different amounts of compression.

FIG. 38.—FOOT-POUNDS MACHINE.

Foot-pounds Machine.—Acting upon this reasoning, Lieutenant Quinan, of the U. S. Army, devised an apparatus which is shown in Fig. 38.

It consisted of three boards, so connected as to form a slide 16 feet high, in which a weight (the shot of the pressure gauge) could fall freely. One of the boards was graduated into feet and half feet. The horizontal board at the bottom, upon which the others were nailed, rested on a heavy post set deep in the ground. A round tenon formed on the top of the post projected through a hole in the board. On the top of this tenon, turned bottom upwards, was placed the piston of the pressure gauge. This served as the anvil, and on it the plugs were placed. The fuze hole of the shot was plugged with a large wire, which projected through the top and gave a hold for a simple form of clutch, by means of which and a light rope passing over a pulley at the top of the structure, the shot was hoisted to any desired height. The clutch was released by hand from the steps of a ladder.

With this apparatus the uniformity of the plugs is tested. It was found that plugs cast separately in mould were of no value for these tests, and had to be rejected. The plugs cut from drawn lead gave satisfactory results. These plugs were carefully measured before compression and *again after* compression, by taking the average of several measurements. The difference between the original length and the reduced length gave the compression caused by the blow of the shot in falling. The instrument used in measuring the plugs is the micrometer calipers shown in Fig. 39 (manufactured by Messrs. Brown and Sharp, of New York).

FIG. 39.—MICROMETER CALIPER.

This instrument is exceedingly accurate and convenient: it reads to the thousandth part of an inch, and even this space can be readily divided.

The more uniform structure of the drawn plugs, as compared with the cast, is apparent in the different appearances of the two after reduction in the pressure gauge, or in the foot-pounds machine. The drawings (Figs. 40 and 41) show this better than description. Having adopted the drawn plugs, Lieutenant Quinan constructed a table for converting the compressions of the drawn plugs into foot-pounds, or actual measures of the strength of explosives. This was simply and expeditiously done by making several series of experiments in dropping the shot from various heights, beginning with a half foot and going up a half foot at a time to about 16 feet. An average of all the compressions at a given height was assumed as correct.

FIG. 40.—DRAWN LEAD PLUG AFTER COMPRESSION.

FIG. 41.—CAST LEAD PLUG AFTER COMPRESSION.

The height multiplied by the weight of the shot gave the foot-pounds corresponding to that particular compression.

Diagram for Measurement of Pressure.—To more graphically represent the relations between the plug compressions and foot-pounds, as well as for convenience in work, Lieut. Quinan constructed a diagram, using the compressions as the ordinates, and the foot-pounds as the abscissæ of a curve. This diagram is shown on a much reduced scale, and without detail, in Fig. 43.

The extreme co-ordinates are fixed by nitro-glycerine.

The original diagram 21 × 14 inches, has been relied upon for converting plug compressions into foot-pounds, or units of strength.

FIG. 42.—SECTION OF PLUG SHOWING REDUCTION IN PRESSURE GAUGE.

In using the diagram, the figures in the "scale of plug compressions" represent thousandths of an inch. The amount of compression received by the plug is ascertained by deducting its measurement after coming out of the pressure gauge from the measurement made before explosion. The difference is, of course, the compression received, in thousandths of an inch. Find the point in the "scale of plug compressions" corresponding with the amount of compression ascertained. From this point follow the perpendicular lines until the curved line is reached. Then from the point in the curved line so reached follow the horizontal lines to the "scale of foot-pounds." The figure there reached is the equivalent in foot-pounds of the compression.

The standard charge for this pressure gauge is 24 grains.

This system gives a comparative measure for high explosives. This pressure gauge is not, however, an accurate test for lower explosives. A triple charge of good black blasting powder fired with a fuse will produce a scarcely perceptible effect on the plug, and yet we know that this powder is capable of great *work* in certain kinds of rock. We may suppose, without an error affecting our principle, that, in firing 24 grains of high explosive, the product of the amount of gas multiplied by the temperature of the gases gives a number equal to the product of the corresponding elements in the explosion of triple the charge of black powder. But in one experiment we get a compression which is almost infinitely greater than in the other; for in the last we get a result too small to be measured. It is because the third factor in our formula for explosive effect—time—bears a similar but inverse ratio in the two cases; in the first being inconceivably short, and in the second case a sensible interval.

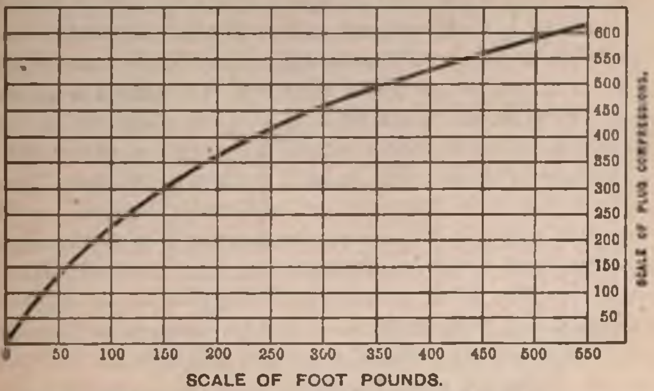

FIG. 43.—QUINAN'S DIAGRAM FOR MEASUREMENT OF PRESSURE.

In the explosion of the black powder, the force, though great, is developed so gradually, that at no one instant is enough inertia developed in the shot to produce a sensible compression of the lead.

Initial Detonation.—I have already referred to the relative value of quick and slow explosives. Given a particular piece of work to be accomplished, it may well be that of two explosives available, the more powerful one may, for want of quickness of combustion, be the less efficacious for the purpose in view. This drawback of the slow action of the more powerful explosive may be overcome by adopting the method of firing explosives which is known as the *detonating ignition.* It consists in applying a *strong local explosion* instead of a spark or flame.

It is especially in connection with nitro-glycerine that this mode of ignition has led to remarkable results, and it was to suit the peculiar nature of that substance that it was invented. Nitro-glycerine, indeed, without that special firing, though it is an explosive, is not a blasting agent, as it cannot be applied with any degree of certainty that it will go off. Not so when fired by a local explosive. It not only detonates without any confinement, but it affords an extraordinary facility for setting off substances which, without its aid, are absolutely inexplosive. If, for instance, charcoal and nitrate of potassium are mixed without sulphur, they form no explosive compound within the ordinary meaning of that term; but if from 10 to 15 per cent. of nitro-glycerine is added, a local explosion, produced by a strong detonator or fulminate cap, will cause the almost inert mixture to detonate with nearly the same rapidity as the nitro-glycerine itself. Nitrate of ammonium and charcoal, with or without sulphur, form a mixture so sluggish at the ordinary temperature, that when tried in a shell along with 6 oz. of gunpowder, the explosion of the latter failed to set it off, or even to inflame it; yet mixed with 15 per cent. of nitro-glycerine, it detonates with an extraordinary violence. Sawdust, bark, resin, starch, sugar, glucose, flour, dextrine, gum, &c., mixed with any nitrate, become, if a small portion of nitro-glycerine is added, most violent detonating fulminates. Nor is that all. Substances considered as absolutely incombustible will form explosives; for instance, chloride of ammonium, mixed with nitrate of potash and nitro-glycerine, will decompose explosively under formation of chloride of potassium, and the freed hydrogen unites with oxygen of the nitrate. Sulphates are very much more sluggish; but if very finely divided and mixed with charcoal, they also indicate a decided reaction, although too slow to be completed in the extremely short time which an explosion occupies. Chlorate of potash mixed with nitro-glycerine detonates even without the presence of charcoal or any other combustible. The number of organic compounds, soluble or even insoluble in nitro-glycerine, which can thus be brought to detonate is almost unlimited.

In practice it will be found of great advantage, when blasting large charges of ordinary mining powder, to fire them with a primer of dynamite or gun-cotton. The initial detonation will cause a more rapid combustion of the gunpowder, and tear the rocks asunder with more certainty than when the powder is fired with an ordinary fuze. This causes a more gradual development of gases, which in some cases are not capable of overcoming the resistance of the rocks, and the charge becomes smothered without performing its work.

This extraordinary influence which the presence of nitro-glycerine exercises on slow explosives, and even seemingly inert substances, is easily accounted for. Being a liquid, it comes in very close contact with the mixtures, and when the detonation ensues the fine layer of nitro-glycerine which adheres to every grain is instantaneously converted into an extremely dense atmosphere of gas, having a temperature of at least 3000° to 4000° C. Such a bath must quicken even the slowest combustion. This explains the great success of Judson's powder, where the dope is mixed with only 5% of nitro-glycerine, forming quite a formidable explosive.

It is exactly the same cause which makes gunpowder burn with extreme quickness in a gun, while its combustion in the open air is comparatively slow. When confined the hot gas accumulates in proportion as it is being generated, and the denser it grows the more heat it brings to bear on the reaction, which thus becomes almost instantaneous.

The action of the detonator cap in setting off nitro-glycerine and other explosives is far more complicated, and not so easily explained. Some attribute it only to the heat produced by compression, some only to the heat of the gas given off by the fulminate of the cap, and others, again, to the dissociating power of a strong vibration. It is not unlikely, at least in some instances, that all those influences are brought to bear on the explosion, but it would be very difficult indeed to compute the part contributed to each. There can be no doubt as to the dislocation of certain unstable compounds by vibration alone, since the slight shock which sets off chloride and iodide of nitrogen, perchlorate of ethyl, &c., cannot possibly raise their temperature, even locally, to the degree at which they explode. Even in the case of nitro-glycerine, which exhibits no such extreme sensitiveness, direct experiments have shown that very violent vibration can cause it to explode. But if vibration alone suffices to set off nitro-glycerine, it is still less doubtful that heat alone will do it. Not only does it detonate by being raised to the temperature at which its constituent elements associate, but a minute charge of gunpowder, so slightly confined that the gas which it produces has a very feeble tension, never fails to make it detonate. It suffices, indeed, to apply heat in any shape, so that it acts upon a very large surface of nitro-glycerine, or then the gas evolved can no longer escape as quickly as it is produced, and the pressure, accumulating with immense rapidity, brings on the explosion.

Nitro-glycerine preparations and gun-cotton go off easily under the influence of a sharp local explosion, such as produced by a fulminate. Two opposite tendencies are here at work, with one to set off the explosive, acting on it by heat, vibration, or whatever cause it may be, and the other to throw it away by the propelling impulse due to the expanding gas. Both must be extremely quick in operating, and it is therefore easy to see how a slight, apparently insignificant, difference may turn the scale and cause an explosion or a miss-fire. For instance, in grinding chlorate of potassium and sulphur with care in a mortar, a series of small detonations take place, which do not spread, but a somewhat stronger blow or friction will set off the whole. Evidently in one case the propelling power is preponderant over the igniting tendency, in the other it is not. Even the quickest substance requires time to get heated, and unless the velocity implanted allows that time combustion cannot take place.

Sir Frederick Abel found by repeated experiments that a charge of fulminate amply sufficient to set off compressed gun-cotton failed to explode the same material in a loose form ; but by twisting loose uncompressed gun-cotton round the cap, and securing it well with a string, so as to increase its density and resistance to projection, it is brought to detonate with great facility without increased charge of fulminate. It has also been found that loose gun-cotton detonates more readily if impregnated with quite inert substances than in its isolated state, evidently because the additional weight opposes additional resistance to motion, thus allowing time.

The reasoning which led to firing slow explosives by local detonation was this: When a hammer strikes a very thin layer of nitro-glycerine on an anvil, the blow produces a strong compression of the liquid, which liberates heat, and raises its temperature to the point at which it detonates. But only that part which actually receives the blow explodes. If, however, the hammer is very heavy, and the blow strong, the explosion is not confined to the part which receives the direct shock, and the whole goes off. A local detonation, owing to the immense tension of its gas, must be very similar in action to a strong blow, and it will thus compress the explosive liquid which surrounds it, causing it to detonate at will, and to propagate the explosion throughout the whole mass by the same means. When firing large masses of ordinary mining powder, or Judson powder, it is always best to use a dynamite primer, as better results are obtained, owing to the more rapid and complete combustion of the powders.

CHAPTER XIII.

CONDITIONS TO WHICH MODERN EXPLOSIVES SHOULD RESPOND.

CONDITIONS of Strength—Quick Explosion desirable for Blasting—Internal Resistance to Detonation — Conditions of Safety— Immunity against Fire — Decomposition—Leakage—Deliquescence—Unstable character of Deliquescent Explosives—Resistance to High Temperature—Insensitiveness to Friction, Shocks, and Jars — Resistance to Percussion, Concussion, and Tamping—Purity of Explosion Gases—Detection of Nitro-glycerine in the Human Body—Precautions during Manufacture of Explosives — Explosions due to External Causes — Action of Explosives Department of Home Office.

Conditions of Strength. — The strength of a nitro-glycerine explosive is influenced by several things :—

1. By the amount of nitro-glycerine present.
2. By the amount of gas in proportion to the solid matter appearing in the explosion.
3. By the kind and character of the gases.

With the dynamites the strength is not proportionately dependent upon the amount of nitro-glycerine. It will be found that within certain limits an increase or decrease of the nitro-glycerine will affect the strength of the dynamite but little. Any inert substances used in the explosive will appear as such in the explosion; but this is not the case where the absorbent is an explosive base or dope, as in such dynamites a large amount of the power developed is contributed by that explosive base. An approximate estimation of this power can be computed by the mortar test, and for that purpose it suffices *to make out* the quantity of nitro-glycerine contained in a compound, and compute the distance of projection to which it would carry the projectile of the testing mortar. Then fire a shot with the compound containing the explosive base: the balance of projection is due to the other ingredients, and permits of a tolerably near estimation of their relative power. It is true that the gaseous products of the exploded nitro-glycerine and those of its explosive partner may react on each other, and cause a slight loss or gain of power, but it cannot materially alter the relative value of the two components.

Quick Explosion desirable for Blasting. — Under certain conditions, otherwise similar, a quick explosion is preferable to a slow one for blasting. The same amount of expansion is produced in either case, but the maximal tension of the gas developed may be vastly different, and on that tension depends the blasting power. For instance, mealed gunpowder under certain conditions burns with a tension scarcely sufficient to burst a straw, yet the same substance, under other conditions, becomes capable of tearing the hardest rock. The difference in action is due only to a difference in the rapidity of combustion.

It is therefore clear that, of two explosives, the more powerful one may, for want of quickness of combustion, be the less efficacious for blasting. It becomes then a matter of considerable importance to possess a ready means of overcoming the drawback of this slow action, and as already explained (page 146), the difficulty is met by means of *strong local explosions*, either with *strong detonators* or with *primers*.

Internal Resistance to Detonation.—An explosive which is carefully compounded with reference to the chemical relations of its elements, and which gives in theory a nearly perfect resolution into gas, sometimes fails to show the strength naturally expected. This leads to the theory of internal resistance to detonation offered by different substances. *Lieut. Quinan*, in a discussion on this very interesting phenomenon, remarks: "In being converted into gas, the cohesion of the particles, as well as the chemical attraction which unites the atoms, must be overcome. Work expended in this direction is lost in overcoming external resistance, or in strength, as shown by the pressure gauge. The work done in the drug-mill in reducing the ingredients to dust is saved to the explosive, and reappears in its greater efficiency in breaking rock."

Conditions of Safety.—*Immunity against fire* exists only to a certain extent. The statement that dynamite can be set on fire, and that it will burn away without exploding, is not quite correct, and is a very broad assertion. There have been instances where large quantities have taken fire and burned away without exploding, but unfortunately there have been instances also where large quantities of dynamite have been accidentally set on fire, with most disastrous results. Small quantities, and sometimes even large ones, may possibly burn away with immunity, but there is always the danger that the burning explosive will heat the portion not ignited to its exploding temperature, especially when in large masses. One of the peculiarities of dynamite is that it burns or takes fire at a lower temperature than its explosion temperature, and this accounts for its property of burning some time away without exploding.

Decomposition.—In order that the explosive may be kept and stored with safety, it must be free from any tendency to decompose. It will not decompose if it has been properly made and purified. The effect of a high temperature is to mature the seeds of decomposition, if they exist. Chemical decomposition is productive of heat, which sometimes leads to ignition and explosion.

Decomposition, in all classes of nitrated organic compounds, may be thus accounted for: After their nitration a certain portion of acid—sulphuric, nitric, and hyponitric—always adheres to those compounds, more or less, according to their form and structure. From a liquid explosive substance the acids are easily washed out, by churning it with water first and then with alkaline solution. It is quite clear that if the last traces of acids are not perfectly washed out, *and that* if especially hyponitric acid is present, which is a highly corrosive material that attacks almost every organic compound, even at the ordinary temperature, it has to be removed; if not, it will slowly, but surely, lead to incipient decomposition, which, acting on a nitrated substance, sets free portions of dioxide of nitrogen or hyponitric acid.

From nitro-glycerine the corrosive acid is washed out with the utmost facility, and from the moment when the importance of that operation became fully appreciated it has never been neglected. Hence the chemical stability exhibited by dynamite under all conditions of climate. It sometimes indicates an acid reaction; but that is due to the absorbent, and not to the slightest trace of hyponitric acid present.

Leakage.—The most important quality for safety is that the nitro-glycerine shall not leak out of the powder. This is a practical return of the nitro-glycerine to the liquid condition, and if it leaks it is a failure as a safe explosive. Besides being a direct loss of strength, leakage is the source of a great many accidents. The exuding nitro-glycerine saturates the paper cartridges, the sawdust surrounding them, oozes through the crevices of the boxes, gets into the holds of vessels, the floors of cars, the walls of magazines, and a hundred other improper places, where it may cause an unexplained accident. The effect of high temperature is to make the nitro-glycerine more fluid, and nitro-glycerine explosives are more liable to exudation in warm than in cold weather.

Deliquescence.—If deliquescent salts, or other substances which attract moisture, are present, the explosive becomes sensitive to hygrometric and thermometric changes. The effect of a deliquescent salt like nitrate of soda in absorbing moisture in damp atmospheres is, however, not the only argument against it and similar salts.

The theory of deliquescence involves other and more important considerations. The great aim of any manufacturer of explosives should be to give a stable, reliable and uniform character to the powder or explosive he brings before the mining public. If we could know beforehand the conditions to which each case of explosive and each individual cartridge in it shipped from the factory would be subjected, the problem would be easier. If we could know that the explosive would not be subjected to atmospheric changes, the temptation to use a cheap and powerful agent would be irresistible. But we have no right to assume this. Explosives are frequently exposed to the weather, sometimes frozen, sometimes heated rapidly by thawing; now rained upon, now warmed by the sun's rays, now they are transported in ships over oceans where the air is charged with a constant, penetrating dampness, and during transit they undergo changes of temperatures, leaving a temperate climate to cross the torrid zones of the tropics, to be carried into a temperate zone again: then to be used in damp mines, and also in atmospheres heated by chemical action in the rocks. Under these varying conditions, an injurious action accompanies the use of deliquescent ingredients. First, when the air is damp the explosive rapidly absorbs water, to the injury of its strength.

Constant atmospheric changes will act so injuriously on such explosives as to spoil them entirely. A deliquescent salt, by absorbing moisture, overloads the absorbents with moisture, and drives out the nitro-glycerine, if such is present in the explosive, a loss which cannot be restored, as well as a source of danger.

In some cases the explosive compound becomes so spoiled that it will not explode at all, and what does the miner think of an explosive which will miss fire, when after many hours of hard labour he has drilled his hole and it fails to do its work? We all know that repeated miss-fires will destroy confidence in an explosive.

But this is not all. There is an additional objection, the theory of which is best illustrated by a very simple experiment. Take a glass of water and place a thermometer in it. We will suppose it indicates 65° F. Drop into the water about half its weight of nitrate of soda. The temperature is rapidly reduced to about 32° F. While the salt is uniting with the water, a large amount of heat is rendered latent, causing a *reduction of* temperature. Supposing the quantity of water used to be one pound, this reduction of temperature represents work expended to the amount of about twenty-five thousand foot-pounds.

Now let us reverse the conditions. Take a quantity of the salt saturated with moisture, and expose it to a drying atmosphere, so that it loses its moisture rapidly. The temperature of the salt is now curiously elevated, for the heat rendered latent before, becomes sensible now.

The progress of deliquescence is thus explained. The air confined in the cartridge contains a slight quantity of moisture, which, in uniting with the salt, causes a depression in temperature, which condenses fresh moisture from the surrounding air, as a pitcher of ice-water condenses moisture on its outside. This being taken up, reduces the temperature still more, and brings a fresh supply, and so on. The process continues till arrested by an outside or atmospheric elevation of temperature, when the action is reversed. In losing moisture, the heat rendered latent is given out, raising the temperature, which causes a fresh loss of moisture, and further elevation of temperature, and so on, till a change in atmospheric conditions arrests this process, and induces the contrary.

Unstable Character of Deliquescent Explosives.—Deliquescence (it is found) gives two different and incompatible characters to an explosive in which deliquescent salts are used, depending upon the particular state in which it is taken: when absorbing moisture it is comparatively weak, and insensitive to blows or compression; when losing moisture it is comparatively strong, and very sensitive to both. The temperature being already elevated, a slight blow will raise it to the exploding point. The compression given by the tamping-rod in compacting it in the bore-hole may be sufficient to cause a premature explosion. These qualities render it unfit to bear climatic changes, and especially dangerous in warm or drying weather. Its constant subjection to chemical action gives it a character of instability conducive to disasters in handling it. An explosive which is safe to-day and dangerous to-morrow is the most dangerous of all explosives.

From what has been said, it will be seen to be not only essential that all explosives should respond to the conditions enumerated, as to

Safety against *fire and high temperatures;*
Safety against *friction, jars, and shocks;*
Safety against *percussion, concussion, and tamping;*
Safety against *leakage or liquefaction;*

but that they stand also the *heat test* of Sir Frederick Abel: and last, although not least, all explosives should stand the *test of time.*

Temperature.—The effect of heat on all explosives is to bring them nearer their exploding-points, and thus to increase their sensitiveness. This heat makes a slight saving of work in explosion—so that all explosives are a little stronger in warm weather. The exploding-point of nitro-glycerine is given by Hill at 356° F. Gunpowder is 560° F. The danger of deliquescent ingredients is not in lowering the firing-point of nitro-glycerine, but of elevating the temperature of the explosive to a dangerous approximation to this point.

FIG. 44.—FRICTION TEST.

Insensitiveness to Friction is so general with nitro-glycerine explosives, that it might be classed with their general properties, and this quality is doubtless due to the action of the nitroglycerine, which has all the attributes of an oil as a lubricant.

The test for friction is to rub the powder between two sandpaper surfaces. One piece is tacked to a board lying on the ground, the other to a block of wood with a long handle. Fig. 44 will show the test better than with any description.

Shocks and Jars.—Safety against shocks and jars implies several different qualities, which, though allied, are not identical.

Percussion.—By percussion is understood the blow received by the explosive when it is struck between hard surfaces, or by a body moving with very high velocity. To test the sensitiveness of an explosive as to its resistance against percussion, Lieut. Quinan has proposed the apparatus shown in Fig. 45, which may be called a percussion gauge.

It consists of a hammer of dense wood, with a steel rod inserted in its lower end. This hammer slides freely up and down in guides set in a heavy block of wood. The anvil consists of a second steel rod, which is set vertically in the block, directly under the hammer. The slide is graduated to tenths of a foot. The weight of the hammer being known, the blow is easily estimated in foot-pounds.

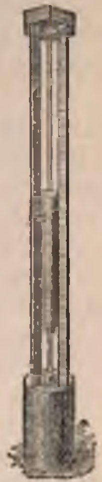

FIG. 45.—PERCUSSION GAUGE.

To get a measure for any particular explosive, a pinch is placed on the anvil, and the hammer dropped from increasing heights until a complete explosion is obtained—the anvil being cleaned and a new pinch used for each blow. For perfect accuracy, the quantity of explosive should always be the same.

Concussion.—By concussion is understood the shock delivered by transmission through air or other medium intervening between the powder and the source of disturbance.

Nitro-glycerine, as a liquid, can readily be exploded by a shock so transmitted. There is danger in producing an explosive sensitive to concussion, and this sensitiveness increases in proportion to the amount of nitro-glycerine present, or the relative approach of an explosive to the liquid condition. This quality can be easily tested by placing cartridges on the ground at certain distances one from the other and exploding one by means of a cap, and if the cartridge lying at a certain distance from it should explode, this second explosion is the result of concussion, and the explosion is called a *sympathetic explosion* or explosion by sympathy.

Tamping.—Sensitiveness to compression is not identical with the properties already considered. The difference can be illustrated in this way: With a resilient explosive, a thin layer placed on an anvil will yield an explosion under a blow which will not affect a thicker layer. A pasty explosive, on the contrary, shows nearly as much sensitiveness in mass as in small quantity. Safety against compression is one of the most valuable qualities an explosive can possess, since it enables the miner, without risk, to properly fill his bore-hole, and to get the requisite concentration of power. An explosive which can be tamped freely will be found much more economical in use than one which is too sensitive to be tamped at all.

The apparatus (Fig. 46) used to test this quality is simple, and at the same time unequivocal as to results. A slide similar to the one used in the foot-pounds machine was prepared for the shot of the pressure gauge. A piece of iron gas-pipe, about 2½ ft. long, its lower end stopped with an iron plug, was fixed vertically in the slide, and supported on a block of iron. To make the test, cartridges of the explosive are slipped into the pipe, and a short wooden tamping-rod placed on them.

The shot is then dropped from increasing heights upon the end of the rod, giving more or less compression, depending upon the heights and number of blows. The weight of the shot being 34½ lbs., the energy of the blow in foot-pounds is easily calculated.

Purity of Explosion Gases.—Theory tells, and practice proves, that at very high temperatures no complex chemical combination can exist. Hence nitro-glycerine, when it detonates, must split up into carbonic acid, carbonic oxide, water, and nitrogen. It is difficult to explain the reason of com-

FIG. 46.—TAMPING TEST.

plaints arising from the use of modern explosives in mines on account of bad fumes, though of their existence there can no longer be any doubt, and the poisonous element consists of hyponitric acid. But such fumes are never the products of a rational use of the explosive substance, and it is quite evident that hyponitric acid can never escape decomposition in an atmosphere of 3000° C. or more with combustible elements in presence.

It does not. But when a dynamite cartridge burns instead of exploding, the combustion takes place at a much lower temperature, and the nitric acid contained in the nitro-glycerine gives off only part of its oxygen, forming dioxide of nitrogen, which escapes, and in contact with the atmosphere gets converted into hyponitric fumes. It is easy to become convinced by actual experiment of the different atmosphere produced by a cartridge when burning or exploding. In the worst-ventilated tunnel twenty cartridges may be detonated without as much molestation as is caused by the burning of one.

An excess of explosives in bore-holes should also be avoided, owing to the quantity of gases produced, as it will be found in practice, that if the quantity of explosive is proportionate to the amount of work it has to do, the gases produced are not so obnoxious as if an excess of explosive is employed.

I have known of cases of asphyxiation from imperfect explosions, and it is imperative, therefore, that proper attention should be paid to ventilation in workings where large quantities of explosives are fired.

Perfect Detonation.—The frequent occurrence of bad fumes in mines proceeds from the general mistake of not securing the detonator cap to the fuze, and the fuze to the cartridge. In charging, the miner under such circumstances easily draws fuze and cap out of the cartridge, leaving them separated, so that the cap cannot possibly exercise its detonating influence. What then takes place is this. Part of the dynamite burns, emitting hyponitric fumes, and part generally explodes under the influence of accumulating heat and pressure.

Thus the charge goes off, but with a far inferior effect to that of a proper detonation, and with emission of a great deal of red fumes of hyponitric acid. A perfect detonation is requisite, and strong exploders ought to be used in preference. In practice it will be found best to use the triple-force caps, even if single force insure a good explosion.

Detection of Nitro-glycerine in the Human Body.—The poisonous character of nitro-glycerine has already been referred to. If in any case the death of a person should be suspected to be due to this substance, the following method will serve to ascertain the existence of nitro-glycerine in the body. Parts of the body, liver, intestines, &c., are extracted with ether or chloroform; a few drops of the extract are placed in a watch-glass, mixed with two or three drops of aniline, evaporated until ether (or chloroform) and water have gone off, and to the residue a drop of concentrated sulphuric acid is added. If nitro-glycerine is present the contents of the watch-glass will assume a crimson colour, due to the reaction between aniline sulphate and nitric acid, the latter having been liberated from the nitro-glycerine.

Precautions during Manufacture of Explosives.—That the manufacture of explosives is dangerous is obvious, for many reasons. The frequency of accidents shows the danger which exists in their manipulations, and even with the greatest care and most proper supervision they cannot be wholly avoided. *Dr. F. H. Jenssen*, in an able paper on the subject, says that accidental explosions can be traced either to—

1. Improper construction and faulty arrangement of the works and machines;
2. Carelessness on the part of the workmen;
3. Maliciousness.

In making nitro-glycerine there is a danger of firing in the converter or nitrating apparatus, and after that comes the danger from overheating when the nitro-glycerine is precipitated. As the acid nitro-glycerine is very sensitive, and decomposes at 100° F., it is essential that the charge in the converter should be run into a very large body of water, and that this water should be changed as soon as possible. Under no circumstances should acid nitro-glycerine be stored over-night. Care should be taken that the pipe lines between the tanks do not cross or approach near steam or hot-water pipes. Accidents arise from the wash waters, since they carry nitro-glycerine partly in suspension and partly attached to the solid impurities in the water. For economy's sake, as well as to avoid accidents, arrangements should be made to catch as much of this as possible before discharging the water; but where the water is run off, it should be led through earthenware or lead pipe by the shortest line to the river, bay or well. If wooden conduits are used, they become saturated with nitro-glycerine and acids. Hence they should be well covered to protect them from the sun, which causes decomposition.

The effect of the sun's rays was seen at one factory where no provision had been made to catch the traces of nitro-glycerine, and where the wash waters ran a short distance over a sandy beach before entering the river. The result was that on a hot summer's day red fumes were observed rising from the ground, and a heavy explosion soon occurred.

Even where wells are used, there is danger from these wash waters. For instance, at a factory where these waters were led through a ditch in rocky ground, it was found that considerable quantities of the explosive had accumulated in the fissures in the rock. Numerous unsuccessful efforts were made to remove this, and finally the ditch was dammed, so as to keep the explosive covered with water. Several years after, the ditch was struck by lightning, and an explosion ensued which damaged the buildings in the vicinity severely, and hurled large masses of the rock to considerable distances. From the sensitive nature of acid nitro-glycerine, it naturally follows that the recovery of the spent acids is attended with great danger.

During a visit to the Pembrey works in Wales a few years ago, I saw that the precaution was taken to lead the wash aters to a pond which was "torpedoed" once a week—that is, a charge of dynamite was lowered to the bottom of the pond and fired, thereby exploding any nitro-glycerine which had been carried there by the wash waters. This (in the light of previous experience just cited) was a very wise measure.

In the making of the dynamite, there is little danger if the absorbent is itself a safe one, and is not too warm, and the proper precautions regarding the use of metal tools are taken. The buildings should be heated by hot water or steam, and the pipes so covered as to prevent the dust from settling upon them, or, if it does settle, they should be frequently cleaned. This dust is a constant source of danger, especially in the making of explosive gelatine, where nitro-cellulose is used in the dry state and finely pulverised. In all the rooms, the windows should be shaded, to prevent the direct sunlight from falling on the explosive. Similar precautions are to be taken in the packing department.

Among instances of maliciousness, a case in point occurred where a quantity of tips from phosphorus matches had been placed in a bag of infusorial earth, and were not discovered until the earth had been made up into dynamite.

Explosions due to External Causes.—*Mr. L. J. Le Conte* holds that dynamite catastrophes are intimately associated with electric phenomena. He has for the past ten years noted the circumstances attending the accidental explosions which so frequently occur on the Pacific Coast of North America, and he has found that, with the exception of such as occur during thunderstorms, the explosions take place during the violent, desiccating, north-wind storms peculiar to the winter and spring months in California, but occasionally happening in midsummer.

These winds (it must be remembered) have a velocity of 50 miles per hour, and a relative humidity of about 20 per cent., but frequently as low as 15 per cent., though seldom as low as 5 per cent. During the prevalence of the winds a prodigious amount of electricity is developed by the friction of clothing, especially when walking against the wind. One can thus easily generate a spark *half an inch long*. The phenomenon is also strongly marked in horses at work, the electricity causing their manes and tails to bristle to a remarkable extent. Mr. Le Conte finds in this electricity the exciting cause of these explosions, and in the *dust* that prevails in the works, the medium through which explosion is propagated, a dust explosion always preceding the explosion of the mass of powder. The explosions occur on the third or fourth day of the storm.

To test his theory, he made four predictions in 1882 and 1883, and in each case an explosion of considerable magnitude occurred. To guard against these accidents, he suggests the use of steam jets, such as have been so successfully applied in cotton and flour mills, and in coal mines.

As explosions during thunderstorms are caused by the return shock, it should be a fundamental precaution that all good conductors of electricity be prohibited from entering any building where explosives are stored or manufactured; and it would be a wholesome rule not to allow such conductors to be anywhere near the premises.

Too much stress cannot be laid on the great services rendered by the Explosives Department of the Home Office in elucidating the causes of accidental explosions, and the reports of Col. Majendie, H.M. Chief Inspector of Explosives, and the other members of the Department, clearly demonstrate that through the searching investigations of these officials a degree of knowledge has now been gained in the art of manufacturing explosives, by which, if absolute safety is not guaranteed, at least the best precautions which human ingenuity can suggest have been introduced; and the decrease of accidents in this country proves, that the efforts of the Explosives Department have not been without beneficial results, in lessening the dangers incident to the manufacture of explosives and their use in the arts and otherwise.

CHAPTER XIV.

GENERAL DIRECTIONS FOR USING DYNAMITE.

Grades of Dynamite—General Rule for its Use—Materials for use in Blasting—Drill Holes, Charges, etc.—Charging with Cartridges—Priming—Tamping—Explosion of Blast—Miss-shots—Frozen Dynamite—Safe mode of Thawing—Precautions.

Dynamite is the article among modern explosives which is now best known and mostly in use. The American name for it is *Giant Powder.*

There are, or ought to be manufactured at each factory, two grades of dynamite, No. 1 and No. 2, also a No. 3.

No. 1 is more powerful than No. 2, and, when gelatinised is not affected by water. It is also much more expensive.

No. 2 is about three-fourths as strong as No. 1, but is weakened by water if kept in contact with it too long.

For the very hardest work, and for cases requiring long exposure to water, I recommend No. 1; for all other cases, No. 2.*

As a key to a clear understanding of the peculiar nature of dynamite and success in its use, I give the following general rule and explanation:—

Rule.—*Let it be put into close quarters, and held there by the most unyielding barricades or confinement at command. Let there be no vacancies about the charge, and let all its surroundings be as compact, heavy, and incompressible as possible.*

The explosion of gunpowder (it may be explained) proceeds progressively by combustion, and its gases gradually accumu-

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* See 'Modern High Explosives,' "Dynamite No. 2," page 67.

late until the resistance to them gives way. This yielding, in almost every case, takes place before all the powder is burned, so that any vacancies are filled with gas at the maximum pressure or density, and no effect is lost. But dynamite does not thus explode. Explosion does not take place by combustion, or progressively; it takes place instantaneously, and all parts of the charge decompose simultaneously, thus making the initial pressure the maximum one. Hence every vacancy withdraws gas sufficient to fill it, and thereby weakens the effect accordingly.

Therefore leave no vacancy about the charge.

Materials for use in Blasting. — *Cartridges.* — In all cases where dynamite is used I recommend cartridges. They are easy to handle, and ready for use, in form shown in Fig. 47. The regular sizes are from 4 to 8 inches long, and from ¾ to 2 inches in diameter. Cartridges of the proper size to suit the diameter of the bore-holes are preferable, but the miner can load the largest hole with the smallest cartridge by slitting them on the side, as shown in Fig. 48, and pressing them down in the drill-hole with a wooden tamping-rod.

FIG. 47. FIG. 48.
DYNAMITE CARTRIDGES.

Caution.—*In tamping powder or explosives, always use a wooden rammer. Never use an iron or steel bar with any explosive.*

From the nature of the substance, dynamite cartridges may be readily cut into such lengths as may be required.

Caps.—The regular cap or exploder, from a triple to a sextuple force cap, is employed to effect the explosion of the dynamite.

Caution.—*If you value your fingers and do not want to lose them, do not go "fooling with the cap" because you want to see "what is in it," or "what it is made of."*

Fuze.—Use the better quality of fuzes, the best is always the cheapest, and as dynamite is often used under water, or water employed for tamping, I recommend the best double tape fuze for regular use. Single tape may be used where you know your ground is only a little wet.

Nippers and Pinchers.—A very convenient little tool for cutting fuze and pinching the cap to the fuze is shown in Fig. 49. By means of the notch S_2, the fuze is cut, and when the same is inserted in the cap, as shown in Fig. 50, with the notch S, the upper part of the cap is squeezed tightly on to the fuze z.

FIG. 49.—FUZE CUTTER AND NIPPER.

FIG. 50.—FUZE AND CAP.

This is a necessary precaution, as caps which are not tightly squeezed on to the fuze often fail to explode.

Funnel.—A tube with a funnel mouth will be useful in charging with loose powder.

Drill-holes, Charges, &c.—As to the diameter and depth of holes, where they should be made, the direction they should take, the quantity of powder or explosive to be used, and many other matters, no precise rules can be laid down for blasting with any explosive. In these things there must be variation according to the location, character of the material to be blasted, the purpose of the blast, and other circumstances too numerous and complicated to anticipate. Much must, therefore, be left to the good sense and experience of the blaster.

The following observations and examples will afford some assistance :—

As a general rule, the drill-holes and charges for dynamite can be and should be comparatively small.

In heavy work the holes should be large in size and less in number, and the amount of dynamite should be in proportion to the work to be done.

A small quantity in a deep hole, whether the hole is large or small; also a small quantity in a large hole, whether the hole be deep or shallow; also a large quantity in a small but deep hole; also a large quantity in a large but shallow hole, are all examples of misapplication. They are all violations of the general rule applicable to all explosives—*that the quantity of explosive should not only be proportionate to the resistance, but the hole should be proportionate to the explosive, or the explosive to the hole.*

Owing to the great difference in the capacity between the old powder and the new explosives, the tendency will be to overcharge; it is, therefore, recommended that each blaster experiment on this point, so far, at least, as to ascertain the minimum quantity of explosives which will answer his particular purpose.

Charging with Cartridges.—*The charge must fit and fill the bottom of the bore, and be packed solid.* This is an essential pre-requisite to an effective blast. The best way to secure it is this: Take a cartridge as nearly as possible of the same size as the bore, and cut it into sections of about twice or three times their diameter. With a hard wood rammer, as large as will run freely in the hole, press these sections into the bore-hole one by one with sufficient force, until each section is driven to the bottom and expanded laterally, so as to fill the hole solidly in every direction. If the cartridge is smaller than the hole, slit it lengthwise. Any size cartridge may be used, provided it is thus put in (see Fig. 51).

Caution.—*Metallic rammers must not be used.*

Priming.—The primer consists of the cap with the fuze in it imbedded in a cartridge of the explosive. The cap may be inserted directly into the charge, only it is liable to get out of place. A convenient way to prepare a primer is this:—Cut off squarely the end of the fuze and thrust it into the cap up to the fulminate. If the fuze is too large, scrape it down, and if too small, wind it with paper. Then clamp the cap to the fuze with the nippers, being careful not to disturb the fulminate in the cap (see Fig. 52).

FIG. 51.—CHARGING.

FIG. 52.—FASTENING CAP.

If for a wet hole, smear the junction of the fuze and cap with bar soap or the like, to make it water-tight.

Now open the end of a cartridge, and with a pointed stick make a hole in the explosive and insert the cap (with the fuze attached) the full length of the cap, and press the explosive firmly about the cap. Next gather the cartridge paper about the fuze and tie it there strongly with a string, so that the cap cannot be withdrawn from the explosive (see Fig. 53). Cut off so much of the cartridge as is not needed, and the primer is complete.

Thus prepared, place it in the drill-hole, and press it with a wooden rod into contact with the charge.

In cases where whole cartridges are required they may be attached, as in Fig. 54.

Tamping.—This is of great importance. The idea prevails to some extent that dynamite "strikes downward" more than upward, and that tamping is useless. This is mere idle talk. *Always tamp if you can*, and with the best materials at hand and in the strongest manner.

By reason of its quickness, dynamite will do a good deal without tamping when gunpowder would do nothing, but this is no reason for rejecting tamping.

In deep and down holes water makes an excellent tamp. A shallow tamp of water amounts to but little. A shallow tamp of sand, brick-dust, or clay is much better.

FIG. 53.—PRIMER.

In driving and packing the tamp next to the primer, be careful not to explode the cap; the first handful of tamping should always be pressed down gently.

In fissures and artificial cracks, surround the charge with mud, clay, sand, or water if possible.

Explosion of Blast.—In most cases it is better not to cut off the required length of fuze until the hole is charged and tamped. Then cut it off at a safe length, and fire. Set fire to the fuze with a match or fusee: the burning of the fuze explodes the cap; the explosion of the cap explodes the primer or charge in which the cap may be. All the other cartridges or charges in the same hole are exploded by the first explosion of the primer (see Fig. 55).

Miss-Shots.—In case the blast misses, remember that the cap is charged with fulminate, and must not be trifled wit Therefore, take out the tamping to within two or three inche of the charge, put in another cartridge, fire it, and its explosio will set off the main charge, unless the explosive had becom frozen in the bore-hole.

Caution.—*Never pick out a shot of powder or dynamite, it is always attended with more or less danger.*

I have always followed the practice, after inserting t primer, to take a piece of old newspaper, make a ball it and push it on top of the primer and then put in th tamping. If the shot misses fire and the tamping has to b scraped out, as soon as the scraper reaches the paper I kno I am near the explosive; and simple as this precautiona measure is, it prevents the scraper from coming in conta with the fulminating cap.

FIG. 54.—PRIMER.

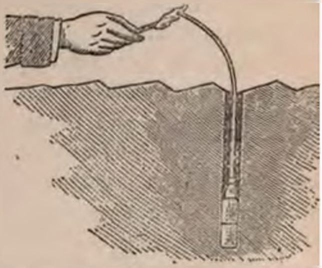

FIG. 55.—FIRING THE CHARGE.

To ensure explosion, the dynamite must not be froze The fuze must be good, and be kept in the cap; the ca must be kept dry, and not be withdrawn from the explosiv Therefore, if there is a miss-blast, find out the cause if yo can, so as to avoid it afterwards, and look for the cause in o of the five things named.

A space of several inches, either vacant or filled, betwee several charges or cartridges in the same hole, will not preve the simultaneous explosion of all.

In case the blast is not effective, it will be because the directions have not been followed, or because the blaster has erred in some matter left to his discretion. The most common causes of failure are deficiency of the explosive and defective tamping. Never spare the explosive because it is dear; put in enough to make good blasts, and then, if dynamite proves too expensive, leave it and use common gunpowder again.

I will repeat here again, that the great advantage claimed for the modern explosives consists, not so much in diminishing the cost of the explosives as an item of expense, as in increasing the amount of work accomplished. The difference in the cost of high explosives and of powder, respectively, is trifling in comparison with the difference in the cost of drilling, charging, tamping, convenience in wet work, and effectiveness of blasts.

Dynamite, as a general rule, throws rock less and breaks it more, and extends its effects much deeper, than ordinary blasting powder; and those who use it soon learn not to judge of a blast by first appearances. It frequently happens that a blast which seems to have had no effect proves to have done remarkable execution in cracking and loosening the rock, and preparing the way for subsequent blasts. This is especially the case in tunnels and shafts.

Frozen Dynamite.—Dynamite freezes more easily than water. When frozen it is hard and cannot be loaded properly into bore-holes, and is difficult of explosion. It must be thawed.

In doing this we encounter one of the peculiarities of the powder, and almost its only practical danger.

You can set dynamite on fire or burn it up without causing an explosion, but you must **never roast, toast, bake, or fry it.** That is, you must not bury it in embers or hot ashes, nor put it in an oven or kettle or other heated vessel, or on boilers or other heated metals, nor set it up before a fire, or expose it to any strong radiation of heat. It must not be thawed or *heated rapidly.*

There is **but one safe mode of thawing it,** which is to keep it in a kitchen or other room at summer heat, and away from the fire, until it is soft. It is then ready for use.

It is better to keep it, during cold weather, where it will not freeze at all. A dry, warm cellar or deep mine will protect it.

If these directions are disregarded an explosion of more or less intensity is liable to follow.

Dynamite manufacturers generally supply special thawing apparatus, which are portable tin or metal pots surrounded with a water-jacket to hold warm water.

Precautions.—Never attempt to thaw frozen dynamite by *roasting*, *toasting*, or *baking it.* Never put it in heated vessels or on boilers, or before fires or heated metals.

Never put a cap into a charge or primer until you are ready to use it. After it is made, never let a primer leave your hands until it is in the hole.

Keep the caps away from the dynamite. Never let them come near each other, except when used.

Never allow smoking or other fire near the powder, or explosive, as it burns rapidly, and especially when loose, and may fire caps incautiously left near by, and thus bring on an explosion.

Never use a metallic rammer.

Do not get nitro-glycerine on your fingers. It will be absorbed by the skin, and give you a headache.

Invariably prepare your primer at a distance from your explosive.

CHAPTER XV.

EXPLOSIVES IN PRACTICAL APPLICATION.

EFFICIENCY of Dynamite in removing Tree Stumps and Boulders—Blasting Tree Stumps—Blasting Boulders—Sinking Wells—Breaking Ice—Breaking Boulders—Removing Piles under Water—Rock Blasting—Tunnelling and Blasting in Headings—Musconetcong Tunnel—Tunnelling with Hand Labour—Königshütte Tunnel—Pfaffensprung Tunnel—Blasting Large Mines—Underground Drilling with Compressed Air.

IF properly used, dynamite will take out stumps of large trees and break up masses of rock more economically than can be done by any other means. In most cases the stump is removed almost entirely from the ground and torn in pieces. The boulders are broken, so as to be easily removed.

Blasting Tree Stumps.—Find with a crowbar the best place between the roots to get under the body of the stump. Do not be afraid of the uphill side: this may require a little more digging, but will afford a better tamp.

If the stump is not too large, a single cartridge, 1½ by 8 inches, well situated and carefully tamped, will take it out.

If the stump is large and deep in the ground, the hole must be larger than will be made by the crowbar.

Dig down by the side of the stump, then make a horizontal hole under the bottom of the stump as near the centre as possible, and just large enough to receive the explosive, disturbing the natural earth as little as possible. Place the explosive close to the wood; then put in the primer and tamp.

The tamp in stump and boulder blasting is of the utmost consequence, much more so than in bore-hole work. The following directions can be varied according to circumstances:

After putting the charge and primer in place at the bottom of the hole and in contact with the stump, ram in a little clay or compact dirt, and then wet it, or use mud for packing. Thus fill up the entire opening. If the charge is well under the stump, this will do; but if it is not—if, as is frequently the case, the charge is only partially under, and especially if it is on the lower side of the stump—make a dam (the larger the better) about the mouth of the hole, and fill it with mud or water.

Remember that the barricade should be as compact and as heavy as practicable. Therefore loose gravel, sand dirt, loam, stones, etc., etc., are of little service. Water or mud, or dampened clay, and plenty of it, is the best.

FIG. 56.—A STUMP BEFORE BLASTING.

FIG. 57.—SAME STUMP AFTER BLASTING.

If the stump has a tap or peg root, put the charge well down and close to this root.

Fig. 56 shows a stump which was removed by blasting; it was a green white-oak stump, 30 inches in diameter, with roots deeply bedded in the ground. To have cut out and dug out this stump, with axe and spades, would have been a hard day's work for two or more good men. A hole was punched beneath the stump, as shown in the figure, with an iron bar, so as to reach the centre of it. Two of the cartridges were placed beneath the stump, and were tamped with some earth; a pail of water was then poured into the hole, which had the effect of consolidating the earth around the charge. The fuze was then fired. The result was to split the stump into numerous fragments, and to throw it entirely out of the ground, leaving only a few shreds of roots loose in the soil. The result is shown in Fig. 57. The fragments of the stump were thrown to a distance of 30 to 50 feet, and many smaller ones were carried over 100 feet. The quantity of explosive consumed was not less than two pounds.

One useful effect of the explosion consisted in the breaking up of the stump into such pieces as could be easily sawed into firewood; by which much after-labour in breaking it up, when taking it out in the usual manner, was saved. This test was perfectly successful, and proved not only the thorough effectiveness of the new method, but its economy in cost and in time. Several other stumps were taken out in the same manner, the time occupied with each being from five to ten minutes. Smaller stumps were thrown out with single cartridges, but in not one case was anything left in the ground that might not be turned out with the plough, or that would interfere with the ploughing of the ground.*

Blasting Boulders.—If you can get the charge under the rock in the manner directed for stumps, do so. If it cannot be placed directly under the boulder, place it as nearly so as you can. Also try to get your charge against the flat or hollow side of the rock, and not against the swell side. Wherever the charge may be, see that it is well supported and surrounded and burdened with water, mud, damp clay, or some other compact and weighty material.

Where there is a crack or cleft, unless it is either too wide or too narrow, it may be made serviceable. The cleft should be packed with damp clay or mud up to the point where the charge is to be. Lay the charge and primer in their place, and fill and pack the balance of the crack with clay or mud in like manner.

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* For further information on the subject see 'Modern High Explosives,' chapter vi., "The Application of High Explosives in Agriculture."

Sinking Wells, &c.—Make a hole with the crowbar to the depth desired, put the charge at the bottom, tamp well, and fire. The effect is perfection : the harder the ground, the better.

Breaking Ice.—If the ice rests on water, place the charge in the water under the ice, and in contact with it. If the ice is apart from water, it must be dealt with according to practice for either a drill-hole or a boulder.

Breaking Boulders.—In a case where a rock of about 150 cubic feet, and weighing about 10 tons, was experimented upon, the shape of the rock before explosion was as shown in Fig. 58. A hole was made with the bar in the ground beneath the rock, and three cartridges were inserted and exploded. The result is shown in Fig. 59. To have produced this by the ordinary method, such as was here done in a few minutes by one man, would have occupied at least two men with drills, sledge, etc., two or three days.

FIG. 58.—THE ROCK AS IT WAS.

FIG. 59.—THE ROCK AFTER BLASTING.

The application of this method is seen to be of great value where the saving of time is an object. An acre of stumps or rocks may be cleared in one day by one or two men, and the material left ready for use as firewood, or as stone for fences or buildings. The cost in money is also reduced in some cases very considerably, and almost absolute safety to the careful operator is ensured. It would be generally advisable to secure the services of an expert, and that the parties who have work of this character to be performed should jointly engage such a man who could either do the whole work, or do it in part, and instruct a foreman or skilful workman sufficiently in a day to perform the remainder. The most favourable seasons for operating upon stumps and rocks are spring and autumn, when the ground is saturated with water. It should be explained that this explosive is not injured by water, although a long-continued exposure to it would affect some qualities of it.

FIG. 60.

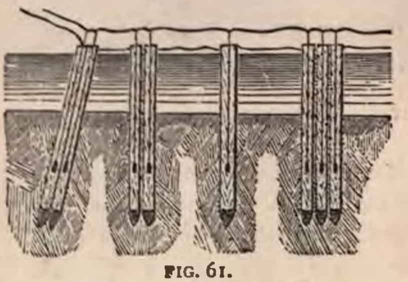

FIG. 61.
PILES WITH CHARGES ELECTRICALLY CONNECTED.

FIG. 62.—PILE CONTAINING CHARGE.

Removing Piles under Water.—A method of procedure in this case, which has been devised by M. Trauzl, the Austrian military engineer,* is represented in Figs. 60, 61 and 62.

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* See 'Die Dynamite.' Trauzl, Vienna.

Twenty-four wooden piles, which had to be removed, were fixed (see Fig. 60) in the river-bed of the Danube, near Vienna. The piles were cut off with the saw just above the level of the water, bored to a depth of 12 feet with an auger 1⅛ inch in diameter, and each hole charged with one pound of dynamite. The dynamite charges were in tin cylinders, and provided with detonators having electric fuzes (Fig. 62). The bore-holes were tamped with water, and the charges were fired by electricity. The explosion brought all the twenty-four stakes simultaneously to the surface, and each stake was completely torn to about 18 inches in height from the bottom of the charge.

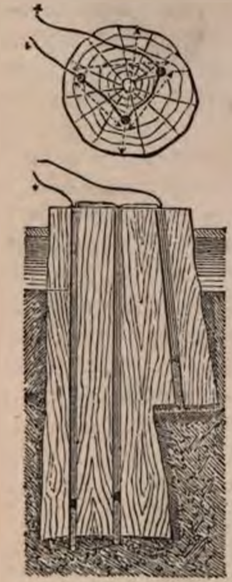
FIG. 63.—STUMP WITH THREE HOLES CHARGED.

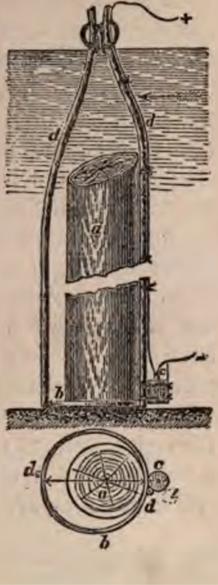

FIG. 64.—EXTERNAL APPLICATION OF CHARGE.

The expense was about one-fifth of what the usual mode of extricating would have cost.

A very interesting example of applying dynamite to a wooden stump under water is represented in Fig. 63. It was removed from an arm of the Danube near Vienna. It measured about 3 feet in diameter at the top, which reached about 20 inches above the water, and was very rotten. Three holes were bored vertically downward to depths of 4½ feet, 8 feet, and 8½ feet respectively, and about 1½ inch in diameter. The boring of each of the deeper holes lasted four and a half hours, and the third three hours. Each hole received a charge of one pound of dynamite, packed in water-tight tin cases. The result of the explosion was a complete loosening of the ground in which the stump was imbedded, so that its removal by mechanical means was perfectly easy.

Where there is no necessity for removing a stake from below the ground, and it is sufficient to get rid only of such portions as stand in the water, no bore-hole is required; the external application of a dynamite cartridge is enough to effect the removal. The method represented in Fig. 64 was applied in a case where the current of the water was so powerful as to prevent the simple laying on of the cartridge. The latter, *c*, was fastened to a wooden hoop *b*, of somewhat larger dimensions than the stake *a*; the hoop was then attached to two strong wooden poles. *d*, *d*, and then pushed over the stake down to the bottom of the river. A cartridge containing one pound of dynamite employed in this manner broke off stakes of an average diameter of 1 foot.*

Rock Blasting.—Rock blasting has to be resorted to in almost all mining operations, such as quarrying, tunnelling, shaft-sinking, railway cuttings. In all such work the bore-holes have to be applied in such a manner that the explosive may act towards the line of least resistance, or the shortest distance from the bottom of the hole to the nearest open face.

If we have an open face *e f*, Fig. 65, as a rule the bore-hole *a b* should not form an angle with the face exceeding 45°. Where ordinary gunpowder is used, if the angle is too great the result

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* See 'Modern High Explosives': "Subaqueous Blasting,' pp. 323 to 357.

will be that the hole will not be bottomed, as shown in Fig. 66, at *f*.

In a rock formation, as shown in Fig. 67, the bore-hole *a b* ought to be parallel with the face *e d f*; and in this case the whole block *e a b f* ought to be thrown out by the explosion of the charge.

The effect of a shot may be influenced, among other considerations, by—

1. The shape in which the rock is presented, the size and number of the open faces, the shape of the piece it is desired to take out (if that is an object), and, of course, primarily, the size of the cross section of the face, if it is heading work.

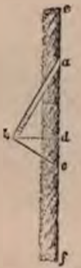

FIG. 65. — APPLICATION OF BORE-HOLES IN ROCK.

FIG. 66.—BORE-HOLE NOT BOTTOMED.

FIG. 67. — BORE-HOLE PARALLEL WITH FACE.

2. The texture of the rock, whether it is hard or easy, firm or loose, whether it is brittle or tough. Thus experience gained in blasting close-grained, hard granite, trap, gneiss, etc., would not apply to limestone, sandstone, slate, etc.

3. The structure of the rock, as to whether it is laminated, stratified, or fissured, upon its cleavage, etc., and upon whether it is massive or broken, etc.

In tunnelling when the strata dip downward toward the face, hence toward the miner, the breaking-in is started at the roof.

If the strata dip from the face; the breaking-in must be started at the bottom.

4. The elasticity of the rock.

5. The explosive used.

6. Whether the hole is to act alone, or simultaneously with or following others. In the case of simultaneous firing, the question arises, as to how the waves of oscillation will best act in concert.

7. The character of fuze and tamping.*

These rules do not apply to blasting with gunpowder only, but may be safely utilised also for high explosives.

In blasting out cuts, work has (in most cases) to be begun on a horizontal plane, or on a slightly inclined surface. For this purpose a series of shallow holes are bored—as at *a*, *a*, *a*, Fig. 68—whose crater faces are enlarged by the application of another series of holes, *b*, *b*, *b*, and then by *c*, *c*, *c*. When this enlargement has reached the depth *d f* and the plane *f h*, we proceed in a similar manner till we have obtained the depth *g j* and the plane *j k*, and so on to *j l* and *l m*.

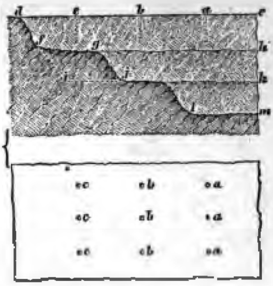

FIG. 68.—BLASTING OUT CUTS.

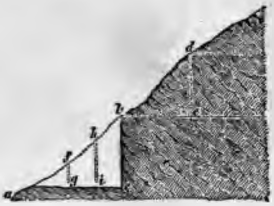

FIG. 69.—BLASTING ON AN INCLINE.

In this way we produce the step-like face *d*, *f*, *j*, *l*, *m*, and the number of miners can now be increased, taking care always to fire shots first on the lower benches, as otherwise the debris from the upper benches would bury the lower ones.

If working on an inclined plane, like Fig. 69, the work is commenced by blasting out with short bore-holes, *f g*. *h i* sections *b c a*, *d e b*, and opening up proper faces like *b*

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* See 'Modern High Explosives': "The Principles of pp. 229 to 263.

which permits of a systematic attack with deep holes afterwards. Another advantage gained by this method is, that several benches can be worked simultaneously, offering great economy in time and money.

Tunnelling and Blasting in Headings.—The system adopted by American railway contractors, in driving railway tunnels, is to advance first with the heading, the full width of the top arch, and then to follow up with the bench work, in such a way that the heading work does not interfere with the bench work. It consists in first blasting out an entire wedge or core the entire height of the heading, and about 10 ft. deep at the centre, and subsequently squaring up the sides by several rounds.

FIG. 70.—HEADING OF MUSCONETCONG TUNNEL.

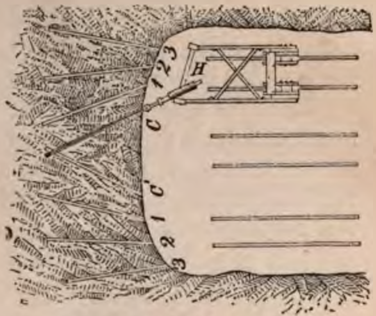

FIG. 71.—PLAN OF THE HEADING.

Musconetcong Tunnel.—This work—which is being cut through syenitic rock, on the Lehigh Valley railway at Easton, in the State of New Jersey—may be described in some detail as an instance of American practice.* Twelve holes are first drilled, by means of rock drills run with compressed air, six on each side, in pairs of two and two, as shown in Fig. 70 at C, A being the floor of the heading. These twelve holes are drilled with from 1½ to 2¾ in. "bits," the holes being on the

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* See Drinker on 'Tunnelling.' J. Wiley & Sons, New York.

face 9 ft. apart, but are drilled convergingly one towards the other, and at such an angle as to meet or cross at the bottom, the largest bits being put in first. This permits the concentration of the powder charges near the vertical centre line of the tunnel within the line of least resistance.

Fig. 71 shows the heading in plan, with the rock drill H mounted on a carriage boring drill-hole C to meet at an angle the drill-hole C′.

When the twelve holes are bored, they are then charged with about 25 lbs. of No. 1 dynamite, and 50 lbs. of No. 2, and are fired simultaneously by electricity. No. 1 dynamite is only used for the centre cuts, inasmuch as in them a quick, strong explosive is required, comprised in a small bulk at the bottom of the holes, where the greatest resistance will be found, while the No. 2 added serves for filling the holes, so starting the sides of the cut as the apex moves. The centre cut being out, a second round of holes is started for the first squaring up, as shown by the numbers, 1, 1, 1, 1, and eight holes are bored nearly in a parallel direction with the centre holes C; these are loaded with No. 2 dynamite and fired. In the subsequent rounds, 2, 2, 2, 2, and 3, 3, 3, 3, the resistance is pretty equally distributed along the whole length of the holes, and is also, of course, not so great as in the cut; therefore No. 2 dynamite is used.

In the first and second squaring-up rounds, from 50 to 60 lbs. of No. 2 dynamite are charged, and in the third from 80 to 90, the holes getting stronger as the arch falls at the sides; there are generally also one or two additional roof-holes in the third round that are not shown in the figure, their position being variable, according to the lay of the rock. The top holes in the first round are also designed to bring down any roof not shaken by the centre cut blasts, and are, therefore, given a strong angle toward the centre, and always drilled from 12 to 14 ft. deep.

The horizontal projection of the above holes is shown in Fig. 83, and as stated before, C, C′ are the centre cut holes; 1, 2, and 3, the square-up holes. As to their relative depth, the holes of the first squaring round are always drilled a foot or more deeper than the cut holes, and when blasted they generally bring out a foot additional of shaken rock at the apex of the cut. The following calculations will approximately show the number and depth of holes required, and the dynamite used for a lineal advance of 10 ft. in heading work :—

12 centre holes	at 10 ft. 6 in.	each, giving	126 ft.	(a)
8 1st sq. up holes	at 12 ft.	,, ,,	96 ,,	(b)
8 2nd ,, ,,	,, 12 ,,	,, ,,	96 ,,	(c)
6 3rd ,, ,,	,, 12 ,,	,, ,,	72 ,,	(d)
2 roof holes	,, 9 ,,	,, ,,	18 ,,	(e)
36 holes		giving	408 ,,	(f)

(a)	total depth of holes, charged with	25 lbs. No. 1 and 50 lbs.	No. 2 dyn.
(b)	,, ,, ,, ,, ,,	55 ,,	No. 2 dynamite.
(c)	,, ,, ,, ,, ,,	55 ,,	,, ,, ,,
(d)	,, ,, ,, ,, ,,	85 ,,	,, ,, ,,
(e)	,, ,, ,, ,, ,,	14 ,,	,, ,, ,,
(f)	total depth, charged with	25 lbs. No. 1 and 259 lbs.	No. 2 dynamite.

Now, allowing the cut holes to be 10½ ft. deep, the cut will generally blast out about 9 full ft. linear, which, as explained above, is raised to 10 in the subsequent rounds.

Assuming the average cross section in an 8-ft. heading to be about 175 ft. for a lineal advance of 10 ft., 65 cubic yards of rock would be broken, which would give an average of, say, $\frac{4}{10}$ lb. No. 1, and 4 lbs. No. 2 dynamite burnt, and a little over 6 ft. of holes drilled, per cubic yard broken.

This, however, it should be noted, would often be increased by occasional block or side holes, and is assumed for a case in which no holes are supposed to have missed, and in which no secondary drilling and blasting are required.

The above estimates are based on ordinary 10 ft. cuts; there were, however, many instances of 12 and 13 and sometimes 14 ft. cuts taken out by ambitious foremen; but even dynamite has its limit of strength, and working cuts too deep is not advisable, as they will often only blow out partially, leaving the rock in an awkward shape.

The "bench work," as the rock enlargement is termed, is kept from 400 to 600 ft. back of the heading, so avoiding any interruptions at the bench from heading blasts, and allowing plenty of room for handling and switching trucks, also for backing the machines to a safe distance from the face when blasting.

Figs. 72 and 73 show the method of blasting adopted in enlarging the rock. First six top holes, from 12 to 13 ft. deep, are drilled and blasted; their relative position is shown in Fig. 74, which is a horizontal projection of the heading: A being a centre line, B the sides of the enlargement, B′ sides of the headings, C face of bench; 1, 2, 3, 4, 5, and 6, the drill holes. These six lift most of the rock; what is left is broken by several horizontal lines shown by B in Fig. 72, in which A is the top carriage with the drill mounted, and B the bottom carriage with drill.

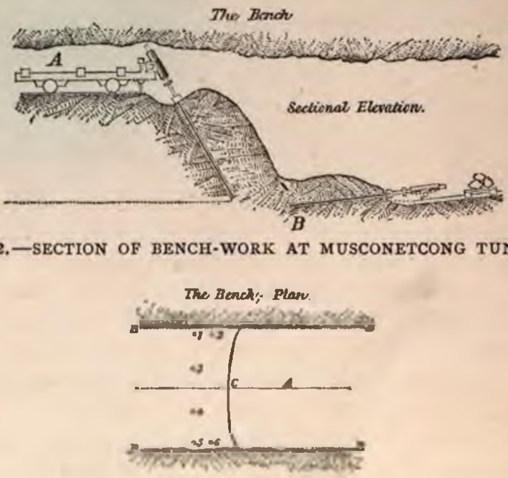


FIG. 72.—SECTION OF BENCH-WORK AT MUSCONETCONG TUNNEL.

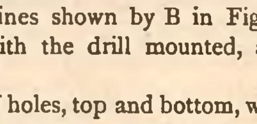


FIG. 73.—PLAN OF BENCH.

These two sets of holes, top and bottom, will average a linear advance for the bench of 9 ft., the following being a fair estimate of the number of feet drilled and powder burnt for 9 ft. advance:

6 top holes at 12 ft. depth, or	72 ft. total depth, charged with	62 lbs. No. 2 dynamite.
4 bottom „ 10 „ „ „	40 „ „ „ „ „	45 „ „ „
10 holes	112 „ „ „ „ „	107 „ „ „

The total height of the cross section adopted for the tunnel through rock, from lower sub-grade (1·75 ft. below base of rail) to roof, was 20·15 ft.; with an 8 ft. heading-off, this leaves about 12 ft. of a bench, with an area of 306 sq. ft., which gives about 102 cubic yards to a lineal advance of 9 ft., or 1·05 lbs. No. 2 dynamite, and 1·1 ft. of holes drilled to 1 cubic yard of rock broken, holes being drilled with from 1½ to 2¾ in. bits, the largest bits being put in first.

Tunnelling with Hand Labour.—When similar work is done by hand labour, the system generally adopted is the following:—

FIG. 74.—FACE OF TUNNEL.

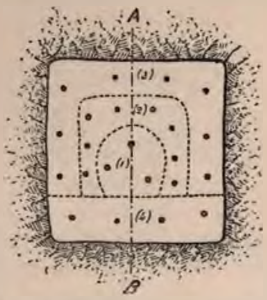


FIG. 75.—FACE OF TUNNEL.

In the centre of the face, Figs. 74 and 75, three holes are drilled inclining one to the other; some miners bore one central hole, but the result is not so satisfactory. These holes are each 2½ ft. deep, and should be fired simultaneously by electricity, which tears out a cone in the centre, shown by the dotted lines in the figure, and around this cone another series of holes is drilled, concentric with the opening in the centre. These shots (2) are fired again simultaneously, then we proceed with series 3, and at last the bottom shots of series 4.

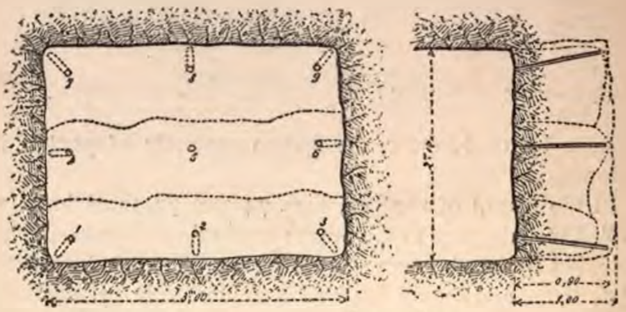
In driving a tunnel having a small cross section, such as is shown in Fig. 76, eight holes are bored 1 ft. to 1½ ft. in depth, and they are all fired simultaneously by electricity.

Another example is given in Fig. 77, representing a small tunnel, say 6 ft. high. Three holes are drilled around the centre as shown in the figure and inclined one to the other at such angles that the bottoms of the two lower ones nearly meet, the third upper hole inclines downward. These three central holes are fired simultaneously by electricity. The central breaking-in hole being produced, the enlargement holes are placed as shown in the figure.

In driving tunnels of larger section, the methods employed vary according to circumstances, and the following examples exhibit some of the best works which have been executed during the last twenty years.

FIG. 76.—FACE OF TUNNEL.

FIG. 77.—FACE OF TUNNEL.



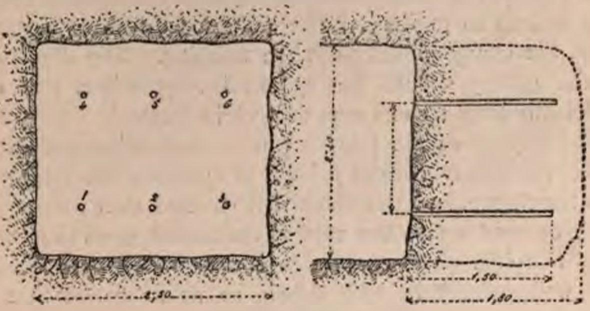
FIGS. 78, 79.—SECTIONS OF KÖNIGSHÜTTE TUNNEL.

Tunnel at Königshütte, Prussia.—This tunnel was driven through very hard sandstone, and the engineer, Hugo Münch, gives an account of the system there employed.

The rectangular section measured 2 m. 10 in height, and 3 metres in width. Nine holes were drilled, as shown in Fig. 78, they had a depth of 0 m. 90, and had a very slight inclination.

The holes numbered 1 to 6 were each charged with 150 grams of nitro-gelatine, and the other three on top with 140 grams each. The ordinary Bickford fuzes and fulminate caps were used for firing.

Shots 1, 2, and 3 were first exploded, which produced a breaking in 0 m. 75 in depth, and 0 m. 60 in height; then 4, 5, and 6 were fired, causing an enlargement from 0 m. 90 to 1 m. 40.



FIGS. 80, 81.—SECTIONS OF PFAFFENSPRUNG TUNNEL.

At last the shots 7, 8, and 9 brought down the rock up to the roof.

One thousand five hundred kilograms of gelatine were consumed in executing the work. If dynamite No. 1 had been used, each bore-hole would have required 280 grams per load, making a consumption of 2520 kilograms, against 1500 k. of gelatine. The economy in the explosive was in the proportion of 3 to 5, and there was a real economy of 10 per cent., taking the price in German marks at 4½ and 3 for the two qualities.

Pfaffensprung Tunnel.—This was in hard granite, 2 m. 20 high and 2 m. 50 wide. Six holes were drilled as shown in Figs. 80 and 81. The holes measured 0 m. 073 in diameter, and 1 m. 50 in depth; and were drilled parallel with the axis of the tunnel. The charges consisted of nitro-gelatine cartridges 0 m. 070 in diameter, and 0 m. 100 in length, and weighed 500 grams each.

Blasting in Large Mines.—For engineering works of great magnitude, where large masses of rocks should be moved at low cost, the most economical method is to make excavations into the quarries and there accumulate a large quantity of explosive, which is fired simultaneously.

In such cases a chamber is generally excavated at the end of a gallery, the length of which depends on the effect which it is desired to produce. The gallery is driven in zigzag, to avoid the charge blowing out the tamping. The dimensions of the gallery should be as small as possible, and only sufficiently large for one man to work in them.

The explosives are piled up in an excavation made at the end of the gallery, several primers of dynamite are introduced into the charge, and the whole well covered over with bags of earth or sand up to the roof of the tunnel, so as to ensure a good tamping. The excavation is now walled up in masonry and well packed in with débris, so as to ensure that the explosives are under close confinement.

Blast of Rock at Genoa.—In 1884 the Italian Dynamite Company fired on this principle a large blast in the port of Genoa, and particulars of the operation have been published.*

It was a question of blowing up a rocky hillock, *a*, *D*, *f*, *C*, Fig. 82, situated in the port of Genoa, and located between the lighthouse and the inner basin of the harbour. There had previously been excavated from the slope of the hill quite a cut, leaving exposed a steep face 20 to 26 metres in depth, and the bluff above was supported only by eight pillars. The pillars, 1, 2, 3, 4, to the left, were so weak that they were

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* In a report issued in Italy by the Societa dei Dynamiti di Avigliana.

hardly able to bear the weight of the superincumbent rock mass. That portion of the hill which is shown in section in Fig. 83, rested to the right on the middle pillar 5. In the bend of the hill to the right of the quarry, the pillars 6, 7 and 8 supported the hill.

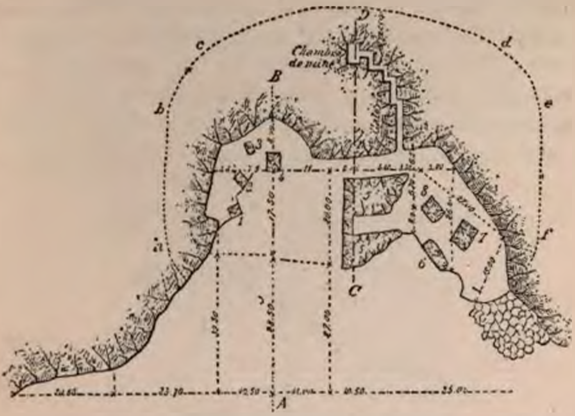

FIG. 82.—PLAN OF BLAST OF ROCK IN PORT OF GENOA.

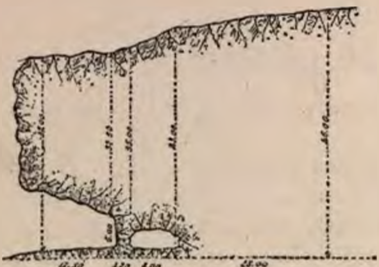

FIG. 83.—SECTION OF BANK OF ROCK.

At a height of about 28 metres (see Fig. 84) a tunnel was driven horizontally, but in zigzag, as shown in Fig. 85. Its dimensions were 1 m. 50 high by 0 m. 90 wide, and at each turn, the bends which made the zigzag were cut at right angles. At the end of the gallery a well was sunk, 8 metres deep and 1 metre in diameter, which at the bottom was so enlarged as to form a mine chamber of 5 cubic metres contents.

To make the charge, sacks coated with paraffin were employed, and they held each 42 kilograms of dynamite. A line of workmen was ranged along the tunnel, and they passed the sacks one to the other, to the underground mining overseer, who placed the sacks in the mine chamber, pressing them tight one against the other. After he had placed one layer at the bottom, a box with gelatine dynamite was placed in the centre, containing two primers, one provided with an electric fuze, and the other with an ordinary Bickford fuze. The mine was now filled with a total weight of 5000 kilograms of dynamite, and sacks filled with sand were placed on top of it to fill the chamber, then loose sand was poured in till the shaft was completely filled for its total depth of 8 metres. At the tunnel end pieces of timber were piled up, and on it a coating of cement. At every turn of the zigzag a barricade of timber was built up, which was walled up with masonry, so as to ensure the complete confinement of the explosive.

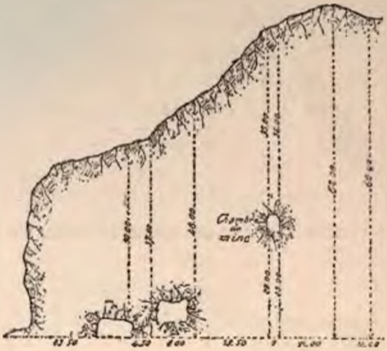

FIG. 84.—SECTION OF BANK OF ROCK.

The result on firing the mine was the complete breaking up of the hill-side up to the contour lines *a*, *b*, *c*, *d*, *e*, *f*, shown in Fig. 82, and the cubage of rock loosened by the blast was estimated at 120,000 cubic metres. There was no projection.*

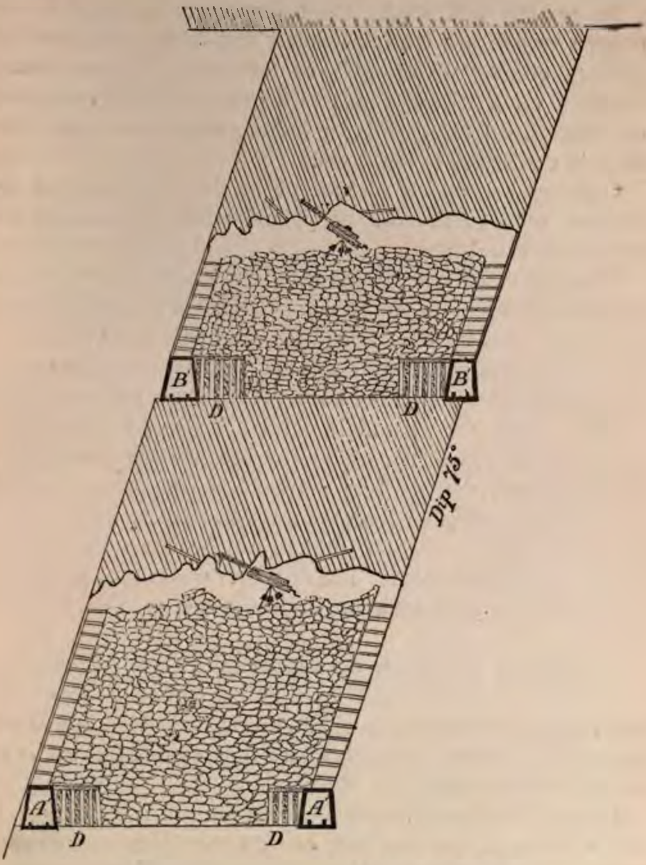

FIG. 85.—STOPPING ORE IN AN IRON MINE.

Underground Drilling with Compressed Air.—In most mines where a large output of mineral is obtained, the

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* For further information on the subject of big blasts, the reader is referred to 'Modern High Explosives,' pp. 271 to 292, where the details of such work are fully given.

drilling is done by machine drills, owing to the rapidity with which these perforators work in comparison with hand labour.

In tunnels and shafts these drills are clamped to iron columns which are easily mounted and dismounted, but when stoping either "overhead" or "underhead," the drill is mounted on a tripod, which also can be shifted easily from one place to another. Fig. 85 shows a cross section of an iron mine in the State of New York.

Galleries are driven on various levels along the foot and hanging walls of the ore body, and which all connect with one main central working shaft.

These galleries run parallel with one another, and at stated distances, about every 200 feet, are connected by means of cross-cuts driven transversely through the ore body, which varies from 40 to 60 feet in width; this ensures thorough ventilation and communication through the mine. A′, A′ show the longitudinal galleries along the second level; B′, B′ along the first level; D, D are the cross-cuts. After the cross-cuts are completed, breaking down the ore from overhead is commenced, and the accumulated ore remains on the mine floor, except such surplus as can be well spared, the broken ore occupying more space than the solid vein stone. The drill goes upwards in proportion as the ore heap accumulates in the mine, as is shown in the figure.

To support the mine, occasional pillars are left standing. There also are shoots built up of timber carried along the foot and hanging walls through which the mineral is dropped into the galleries below, and from where it is carried on cars to the central hoisting shaft.

Ore is mined by this system at 50 per cent. less cost than by hand drilling, and as one drill can do more than many miners could effect by hand labour, the output of the mine is proportionately greater.

CHAPTER XVI.

APPLICATION OF ELECTRICITY IN FIRING MINES.

ECONOMICAL Value of Blasting by Electricity—Sir Frederick Abel's Test —Electric Blasting Apparatus—Magneto Machine No. 3—Directions for Blasting—Influence of Heat on the Conductivity of Gutta-percha-covered Wire.

THOSE who have most carefully studied the question of blasting by electricity are most earnest in praise of the method and of its economical value.

A very little thought will make apparent the greater effect which can be produced by firing simultaneously a number of blasts, instead of firing them singly, while a little experience will teach that even in firing single blasts by this apparatus much can be gained. One advantage gained in firing single holes is, that in case of miss-fire (which happens rarely by this method) no time is lost in waiting, as in the case of firing by safety fuze there would be before approaching the work. There is no "hanging" fire.

A second advantage is, that the explosion of the electrical fuze at the bottom of the charge, where the priming cartridge can be placed, throws the fire through the whole body of the powder, igniting it all at once, and by *detonation*, giving the same charge by far greater explosive effect, as has been fully demonstrated by experiment.

Another advantage is, the explosion of an electric fuze at the bottom of charge produces the first rupture in the rock at bottom of the hole, leaving the tamping perfectly tight, and confining all the explosive gas until the dynamite is completely consumed and its force expended in loosening rock.

When firing is done with a common fuze, the first point of rupture in the rock is often near top of charge, which often leaves a large part of the hole unruptured, the drilling of which and the powder it contained was a total loss, for if it had exploded it would have burst everything around the hole.

The following test, devised by *Sir Frederick Abel*, illustrates very well the different behaviour of gunpowder with the detonating mode of firing:—

"Three small iron cylinders of inch steam pipes, each being 5 in. in length and having a cap screwed on one end, are bedded in the earth, with the open ends level with the surface.

"In the first is placed a charge of fine-grain gunpowder, which is fired by an electric fuze, primed with mealed powder. The powder explodes with a dull report, leaving the cylinder in its place and uninjured.

"The second tube contains an electric fulminate fuze, the remainder of the space being filled with sand. On firing this tube is bulged and cracked a little, but not moved.

"The third tube contains the same quantity of powder as was used in the first one, but it is fired by a fulminate fuze similar to that which was used in the second tube.

"In this case the report is sharp, the cylinder is torn to pieces which are scattered about, and the earth in which it was imbedded is thrown out so as to leave a considerable cavity."

When the charge is very large, it is best, indeed, to place several fuzes at different points, as it is obvious that, whether using fulminate fuzes or others, a great advantage is obtained by a simultaneous firing of the powder at different points instead of firing at one end.

The now well-known effect of the ignition of gunpowder in a confined space is to suddenly convert its solid substance into a great volume of fiery gases of a powerfully expansive nature, which will either speedily find release by rupturing the walls which confine them, or almost as speedily be again resolved, in great part, into a liquid having no expansive tendency.

It is known, too, that a certain though very small interval of time is taken in the passage of the fire through the whole mass of a charge of powder, proportioned, of course, to the size of the charge, its density or compactness, and also, in some degree, to other qualities.

It is also well known that the speed of electricity is many thousand times greater than that of fire passing through any substance whatever, being by comparison instantaneous.

It will readily be seen, therefore, that a great advantage is had, when a charge is fired at many points, and the whole converted into these violent gases simultaneously, over firing at one point, with a comparatively gradual production of the rupturing force.

Electric Blasting Apparatus.—The machine for blasting by means of an electric current which finds the greatest favour at the present time is a magneto-electric instrument of small size, weighing only about 16 lbs., occupying considerably less than half a cubic foot of space, and sold in America at 25 dols.

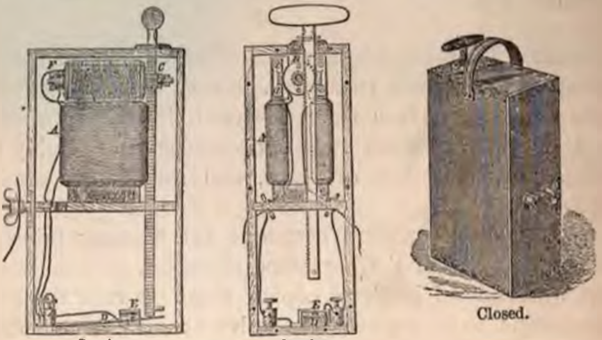
It is constructed on the Wheatstone and Siemens principle, having a magnet of the horseshoe character, of iron, wound about with coils of insulated copper wire; between the poles of the magnet there is fitted to revolve an armature of cylindrical construction, carrying in its body other insulated wire coiled longitudinally, as to the cylinder.

The rapid revolution of the armature, by suitable means, generates and sustains in the machine an accumulative current of voltaic electricity of great power, which at the moment of its maximum intensity is, practically, switched off to the outside circuit in which are the fuzes, and in the interior of each fuze the ignition is accomplished instantly.

In magnetic iron mines the "frictional" machine fails through diversion or dissipation of the electricity, but the "magneto" there works perfectly well; and in submarine or very wet work is also superior, as imperfect insulation is not always an obstacle to its successful working.

The *Magneto Machine No.* 3 here described has fired fifteen fuses—the current of electricity having been conveyed through one-quarter of a mile of bare iron telegraph wire in the water at the bottom of a canal, the fuzes also being immersed.

The capacity of the machine is for about 12 or 15 holes, though under wholly favourable circumstances many more can be fired. The interior arrangement is shown in Figs. 86 and 87. A is the principal magnet; B, the armature revolving between the poles of the principal magnet; C, the loose pinion, its teeth engaging with the rack bar, and by clutching also engaging with the spindle of the armature on the downward stroke (only) of the rack bar; D, the spring, which when struck by the foot of the descending rack bar, breaks the contact between two small platinum bearings, and this causes the whole current of electricity to pass through the outside circuit,—the leading wire and fuzes; E, the two platinum bearings, one on the upper face of the spring, the other on the under side of the yoke over the spring; F, the commutator.



Section.

Section.

Closed.

FIGS. 86, 87, 88.—MAGNETO MACHINE FOR ELECTRIC FIRING OF BLASTS.

The "commutator" is a thin ring of copper like a section of a tube, or would be so were it not divided by a saw cut on each side into two equal parts, which are fastened upon a hard rubber hub. The commutator has pressing upon it (on the outer surface of the ring) two copper springs. These should press firmly upon it, and its surface must be kept bright and clean.

In the course of time, particularly if the machine should not have been used, this surface may become tarnished, then it will be necessary to make it bright. Rubbing with dry emery paper will serve the purpose. Also, small particles of the copper, the result of the wear of the ring or the springs, may fall into the crevices between the two parts of the ring. If these crevices become filled with dust of copper, the result will be to weaken the effectiveness of the machine, as it is necessary that the two parts of the ring should be insulated, and this is the reason of the hard rubber hub.

In order to cleanse this ring or commutator, the rack must be taken out of the case, which can be done by removing the small pin near the lower end of the same. Then the interior works of the machine, with the shelf on which they rest, can be moved partly out of the case—far enough for the purpose. Having done this, remove the springs which press upon the commutator, and then remove the yoke which holds in place the spindle upon which the commutator runs, when the latter can readily be cleaned and replaced.

In very few of the machines has there been any necessity found for this cleaning process, and these minute directions are given, not because they are very likely to be needed, but to save to the person using a machine the trouble and delay caused by having to return it to the makers, from perhaps a great distance. The spindle bearings front and rear will need oiling occasionally.

Fuzes.—The platinum fuze, which is used with the magneto machine, is shown in section in Fig. 89, nearly of the actual size.

A is the shell, of copper, having a raised rim, thrown out from the inside, which holds the sulphur cement more firmly in place; B, the chamber containing the charge of explosive, composed mainly of fulminate of mercury—very powerful; C, the fuze wires, of copper, entering the shell, having a covering which is a partial insulator sufficient for all ordinary purposes; D, the bare ends of the copper fuze wires, projecting above the sulphur cement and into the charge; E, the small platinum wire, or bridge, soldered to and connecting the two ends of the fuze wires: this is heated to redness or combustion by the passage of the electric current; F, the sulphur cement holding the fuze wires firmly in place.

The fuzes commonly in use have wires of 4, 6, and 8 feet in length; any required of greater length of wire are specially made. Those in general use are all of cotton-covered wires, but gutta-percha covering is sometimes required. This nicety of insulation by gutta-percha covering, however, is not needed for general work, but only where blasting is to be done in deep water—probably, indeed, not then, unless several fuzes are to be fired simultaneously through a great length of submerged wire.

FIG. 89.—PLATINUM ELECTRIC FUZE.

Leading Wire.—Enough wire is needed with each machine to make two leaders, of sufficient length to reach from the blast to a safe distance for the person to stand who is to set the machine in operation. Five hundred feet is the quantity usually adopted, but in some cases a thousand have been used.

Connecting Wire.—This is sold in coils of one or two pounds weight, and is used in connecting the fuzes with each other where several charges are to be fired simultaneously.

Wire Reels.—As after use the leading wires may become entangled, and to facilitate the playing out of the wires when preparing them for use and in shifting them from blast to blast, a little apparatus is used called the blasting wire reel. It consists of a strong hard wood box, with a double reel inside, so adjusted that, by means of a connecting rod on the flange of each wheel, easy and speedy connections can be made with the battery in use. To this rod the leading wire is permanently connected, and is always ready for use. It is but the work of a moment to run out as much leading wire as is wanted to connect the battery, and fire; and then as quickly wind up again. The reel by means of a strap is carried around the neck of the man.

Directions for Blasting.—A fuze should be used with the wires attached, of such length that the ends may protrude from the surface after the hole is charged, the fuze head being in the centre of the charge.

Tamp with dry sand, or in such a manner that the wires may not be cut or the insulated covering upon them be injured. When all the holes to be fired at one time are tamped, separate the ends of the two wires in each hole, joining one wire of the first hole with one of the second, the other or free wire of the second with one of the third, so proceeding to the end or last hole.

FIG. 90.—CONNECTING WIRE.

FIG. 91.—MINES ELECTRICALLY CONNECTED.

If the wires attached to the fuzes should not be long enough, use connecting wire for joining. All connections of wires should be by hooking and twisting together the bare and *clean* ends, and it will be best if the parts joining be bright. (Fig. 90.)

The charges having all been connected as directed above, the free wire of the first hole should be joined to one of the "leading" wires, and the free wire of the last hole with the other of the two leading wires. The leading wires should be long enough to reach a point at a safe distance from the blast—say two hundred and fifty feet at least. (Fig. 91.)

All being ready, but *not until the men are at a safe distance*, connect the leading wires, one to each of the projecting screws on the front side of the machine, through each of which a hole is bored for the purpose, and bring the nuts down firmly upon the wires.

Now, to fire, taking hold of the handle for the purpose, lift the rack (or square rod toothed upon one side) to its full length and press it down, for the first inch of its stroke with moderate speed, but finishing the stroke with all force, bringing the rack to the bottom of the box with a solid *thud*, and the blast will be made.

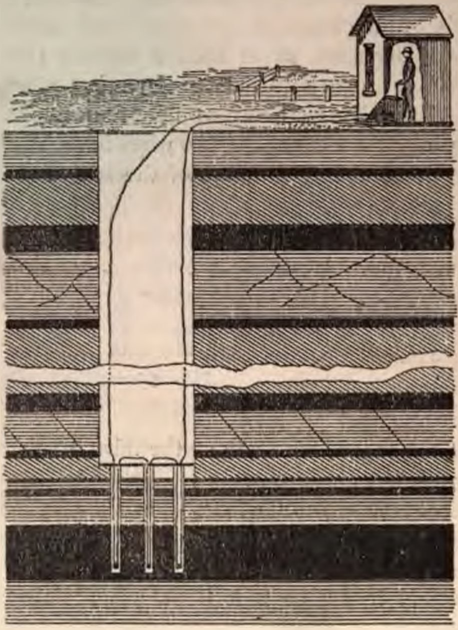


FIG. 92.—FIRING BY ELECTRICITY AT BOTTOM OF SHAFT.

Holes which are fired simultaneously should not be more than their own depth apart from each other; thus, if the holes are 6 feet deep, they should only be 6 feet apart.

It is advisable to place the priming cartridge with the *electric* fuze in it at the bottom of the hole, and leave several inches of the wires protruding out of the hole. In tamping take care not to rub the wires.

Fig. 92 represents a blast of three holes, each 6 feet deep, ready to fire in the bottom of a shaft that may be many hundreds of feet deep. As soon as the operator in the house pushes down the operating rod, all the holes will fire simultaneously, and the result will be as shown in Fig. 93.

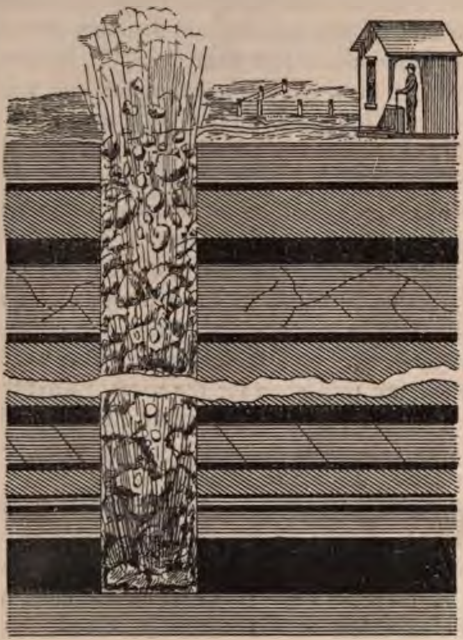


FIG. 93.—THE BLAST FIRED.

Influence of Heat on the Conductivity of Gutta-Percha-covered Wire.—The subjoined remarks on this subject by *J. M. Kostersitz*, Lieutenant-Colonel of Engineers in the Austrian Army, will be found of practical value:—

"It will be well to mention (he says) in advance, that the influence of heat is deleterious to the igniting effect, and the reason of this is in the diminution of the insulating power of the gutta-percha.

"Schellen, in the year 1870, in his book 'On the Electro-Magnetic Telegraph,' says that when gutta-percha is cleansed of its impurities it possesses great insulating power, which decreases with an increase of temperature. Its conductivity at 20° C. is twelve times greater, and therefore its resistance to electricity is twelve times less than at 0° C. At that time no experiments had been made to determine this phenomenon exactly, and its influence on its application to explosive purposes. The impression prevailed at that period that the igniting power was not influenced in any way.

"Water was considered as an element against which the greatest precautions were to be taken, but subsequent experiments disproved this supposition, even if the copper wire was deprived of its insulation in some places. Not alone was it proven that the conducting power of the copper wires is unimpaired by water, but that during very hot weather water affords the greatest protection for the wires. That the igniting effect during hot weather is considerably diminished is beyond doubt, as this fact made itself felt during every experiment carried out during the hot weather.

"At first the supposition existed that the deleterious effect of heat acted only on the electric apparatus, in consequence of the rarification of the air, and this was partially correct.

"Later experiments have proved that the fault is with the wires. The experiments which finally solved this question were finished in the year 1875, and publications of that year recommended as precautionary measures the prevention of the crossing and touching of the leading and return wires, whether they are insulated or not insulated. There was also another danger to be feared, which was if the connecting wires between the different mines should touch one another.

"These connecting wires should not be viewed as a part of the main conducting line, but they should be considered as a part of the arrangement where the equalisation of the electricity takes place. In case these connecting wires should touch one another, and if in consequence of a high temperature the insulating power of the gutta-percha should be diminished, at the point of contact an adjustment of the two electricities takes place which greatly influences the igniting effect, which under certain conditions may result in a miss-fire of all the mines.

"If, for example, we have such an arrangement as in Fig. 94, in which A is the leading and B the return wire, while the dots 1 to 7 indicate as many mines, and if the connecting wire 2 and 3 should cross 6, 7 in *a b*, then it may happen that the equalisation of electricity on the road 1, 2 and 7 may take place, and the mines 3, 4, 5, 6, be excluded from the passage of the electric fluid and miss fire. Therefore the greatest precaution is necessary to avoid contact of the connecting wires, as well as of the leading and return wires.

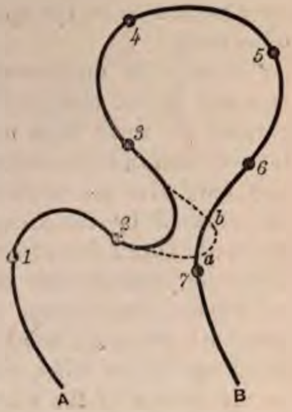


FIG. 94.—CONDUCTING WIRES.

"A case in point took place during the experiments with a new electric apparatus, in which a complete miss-fire of the fuzes occurred. This led to a detailed investigation of its causes. The experiment took place on the 7th of August, 1874; temperature, 20° C.; humidity, 90 per cent.; barometer, 753 mm. Owing to a rainstorm the atmosphere was charged with moisture, and was sultry; the temperature of the air was high. The uncertainty of the weather necessitated making the connections of the fuzes in a hut. The number of fuses was 114. The space was limited, and a contact between a number of the connecting wires could not be avoided. On closing the circuit only two fuzes exploded, nearest to the leading wire. A repetition of the firing met with a similar result, to the great surprise of those present. An examination of the electric apparatus proved its complete efficiency, and the leading and return wires showed no interruption in their continuity, but it was decidedly proved that the hut for the fuze arrangement was too small, and it was impossible, owing to want of space, to completely insulate the connecting wires, so that their contact was unavoidable.

"The fuzes were now taken into the open air, and the trial made immediately on the spot caused the explosion of all the connected fuzes, 114 in number. Further experiments, which were carried on in the open air, always caused the explosion of all fuzes.

"It may be mentioned here that the wooden hut was saturated by the rain, and that some of the connecting wires touched on some large nails, and in this way, by means of the wet boards, a dispersion of the electricity into the ground may have also taken place. This supposition was likewise strengthened by the fact, that in the experiments carried on in the open air some connecting wires were purposely placed in contact with others, and a complete explosion still ensued. Of course the temperature had cooled down somewhat, the grass was wet in which the wires were placed, which cooled the wires, and in consequence the conditions for the passage of the electricity in the open air were more favourable.

"The following experiments were carried out by the military committee in Vienna in the summer of 1875, during the hot days on the 1st, 2nd, and 3rd of July, when the temperature stood at 29° to 35° C.; the moisture varied between 70 and 62 per cent.; the barometer showed only 720 mm.

"The apparatus, contrary to the usual precaution taken with them, were left exposed during the whole day to the influence of the extraordinary heat, as well as the fuzes and connecting wires, whereby the insulating power of the gutta-percha was considerably diminished. Whereas, during the forenoon, the apparatus had a power of firing from 50 to 100 fuzes, on the afternoon of the first day the number was reduced to 30, and on the afternoon of the second and third days only 20 fuzes would explode.

"To find out the cause of this diminution of effect, the fuzes were put down again in the hut, and the effect raised at once from 40 to 60. The same effect was obtained on putting the connecting wires into troughs of water, and they were connected with an apparatus which had been exposed for a whole day to the rays of the hot sun. This experience has again demonstrated the weakening effect which heat exercises both on the apparatus and wires, and has also shown that in placing the wires on the ground or on water, or even by simply covering them with a bad conductor of heat, a good protection is offered, and the precaution must also be taken not to expose the apparatus unnecessarily to the influence of heat.

"The experiments subsequently made on the 10th of August led to the adoption of certain precautionary measures for preventing the defects caused by heat on the igniting power of apparatus and wires. Attention has to be drawn more to the connecting wires than to the leading and return wires, and that especially in those connecting wires which are very close together, an equalisation of electricity may take place, whereby the firing effect is diminished or partly destroyed. By avoiding all contact of the connecting wires, the results obtained were entirely satisfactory, as from 100 to 150 fuzes were exploded.

"Heretofore the cause of imperfect firing was assigned to defects in the apparatus, but these experiments show that it was also the improper application of the connecting wires."

CHAPTER XVII.

USE OF EXPLOSIVES IN FIERY MINES.

SIR F. ABEL on the Prevention of Fire-Damp Explosions during Blasting—A New Method of Exploding Charges in Fiery Mines—Compressed Lime Cartridges for bringing down Coal.

THE use of explosives in coal mines, particularly in those having fiery seams, is a matter of special interest to all who are concerned in the manufacture and utilisation of explosives. It is a recognised fact, that ordinary explosives cannot be employed with safety for blasting purposes in coal mines, where there is more or less fire-damp distributed throughout the workings. Fire-damp necessitates the exclusion of flame, and we know that every explosion is accompanied by an outburst of flame. Coal-dust, also, greatly adds to the dangers arising from the existence of fire-damp in a coal mine, and may even cause explosions, which would not take place but for its presence. This question of fire-damp and coal-dust explosions was felt to be of such paramount importance, that new regulations on the subject were incorporated in the Coal Mines Regulation Act of 1887, which no doubt will prove a great benefit to the workers in coal mines.

The Prevention of Fire-Damp Explosions during Blasting.—The whole subject of prevention of such explosions has been admirably dealt with in some lectures delivered by *Sir Frederick Abel* before the Institute of Civil Engineers. For lack of space I can only repeat some of the most prominent points which have a direct bearing on the subject of safety blasting, as expressed by this eminent scientist. He says :—

"Formidable danger frequently attends the employment of blasting-powder in coal mines, on account of the flame which generally attends, though to a variable extent, the firing of a shot tamped in the usual manner; and especially on account of the large volume of flame which is projected to a considerable distance, either when a blast-hole is overcharged, or when the preponderating strength of the material operated upon gives rise to what is termed a 'blown-out shot,' the tamping being projected from the hole like a shot from a gun.

"The Royal Commissioners recognised the dangers frequently attending the use of powder in coal mines, and the extreme difficulty of effecting any important diminution of those dangers; and they devoted much attention to the question whether it might be possible to discover any powder substitute, or any method of using such substitute, which would secure immunity from danger due to the presence of coal-dust and fire-damp in the localities where blasting had to be carried on.

"Even if undiluted nitro-glycerine is exploded in a shot-hole, the high temperature has the effect of raising to incandescence particles of the tamping employed, or of the stone or coal exposed to the highly heated gases and vapours developed, so that, under any circumstances, sparks would be liable to be projected on the firing of a nitro-glycerine charge. The same holds good with any of the nitro-glycerine preparations known in commerce, such as lithofracteur, blasting gelatine, or gelatine-dynamite; moreover, flame in more or less abundance may be produced by the explosion of some nitro-glycerine preparations, the composition of which includes proportions of inflammable materials.

"That the heat to which very finely divided solid particles may be raised, by exposure to the highly heated products of detonation of nitro-glycerine preparations, is sufficient to determine the ignition of an explosive fire-damp mixture, has been amply demonstrated by experiment, and it is even possible that sparks sufficiently hot to produce that result may be carried to some distance by the blast of heated gases projected by a shot, and thus reach places at some distance from the shot-hole where gas may have lodged.

"In the early part of the labours of the Commission in 1880, I applied the principle of most complete explosion, or detonation, of one or other of the so-called 'high explosives' in conjunction with the method devised by me in 1873, of distributing the operation of the force, developed by small charges of the explosive, over a considerable area, through the agency of a comparatively large volume of water, by which the charge is enveloped.

"The principle of suddenly transmitting the force of detonation of a charge of explosive uniformly in all directions, *by completely surrounding with water* the charge to be detonated, had already been successfully applied by me to the conversion of an ordinary shell into a projectile operating with the destructive effects of a shrapnel-shell, and to several other purposes, and it occurred to me that, by applying the same principle to the charging of a shot-hole, the effect might be not only to modify the destructive action of a high explosive, and thus to attain a comparatively moderate splitting or rending action instead of powerful disintegrating effects, but also to accomplish the extinction, through the agency of the water envelope, of any incandescent particles or sparks, and perhaps flame, projected by the exploding charge, the water being thrown forward together with them, in a finely divided condition. It soon afterwards came to my knowledge that Dr. McNab had previously put into practical execution the idea of extinguishing the flame of a *powder* charge, projected from a shot-hole, by inserting a cylinder filled with water over the charge, and confining it by a small amount of tamping. A series of experiments conducted for the late Commission indicated, however, that water tamping, as first suggested by Dr. McNab, and applied by Settle, used in conjunction with a *high explosive*, such as dynamite, afforded very considerable, if not absolute, security against accidental explosions, under the conditions just now specified.

"The charge of explosive should be placed in a water-tight cartridge, enclosed on all sides by water, with or without the additional use of superposed tamping. The results obtained after a series of exhaustive trials justified the conclusion, that the so-called water cartridge, employed in conjunction with a high explosive, could be relied upon to afford security against accidental explosions during shot firing in the presence of explosive gas mixtures, or of very inflammable coal-dust thickly suspended in air containing some small proportion of fire-damp.

"In constructing a water cartridge there is not the least necessity for employing any device for keeping the explosive in such a position that its circumference is surrounded equally on all sides by the water; it suffices simply to insert the charge, with its waterproofed fuze or wires, attached, into the blast-hole direct (if the latter is in perfectly solid stone or coal, and in a suitable position), or into the cylinder of thin sheet metal, varnished paper or membrane, which is filled with the water; it is best, however, to insert the charge nearly to the bottom of the water, so as to utilise the tamping effect of the greater part of the column. The liquid is retained by a wooden or cork plug, through which the fuze or conducting wires pass, and tamping is applied over this after insertion of a tuft of hay or other suitable padding material.

"Gelatine-dynamite* is especially suitable for employment in conjunction with water, as nitro-glycerine is not displaced therefrom even after long immersion in water.

"The work done in coal by a high explosive, through the agency of a column of water which encases it (or 'water cartridge'), is different in character to that accomplished by the same charge used in the ordinary manner. Instead of exerting a crushing action immediately round the charge, whereby much small coal is produced and no large amount of displacing work performed, the force being distributed over the whole area of the water column, its action is thereby greatly moderated, and the coal is brought down in large masses—the work done extending over at least as large an area as that of the best powder-shots.

* In my opinion, forcite also.—M. E.

"In applying this system as a safeguard against accidental ignition of coal-dust or fire-damp mixtures, the quantity of water used should at least amount to four times the volume of the charge employed. If less is employed, the flame will not be quenched.

"The experiments carried out for the Royal Commission with water cartridges led to the observation, that a considerable proportion of the water was driven forward in a body instead of being dispersed in a very fine state of division, by the force of a *blown-out shot*, and a suggestion was consequently made for the employment of the water in a different manner, which was worked out by Mr. Galloway with most successful results, so far as related to the extinction of flame and spark from a blown-out shot. By distributing the water through a porous body, such as sponge or moss, and thus effecting an initial interruption of continuity of the mass of liquid placed over the shot, its thorough dispersion in a very finely divided condition is ensured, and its extinguishing power is greatly increased. Comparative experiments have shown that the water cartridge did not afford that absolute security against the ignition of an explosive gas mixture by a blown-out dynamite shot which was attained by the comparatively simple moss and water tamping, which can be applied without difficulty even in holes having an upward inclination.

"It may be well again to emphasise the fact, that neither the water cartridge, nor water tamping applied in the manner in which it has been found so thoroughly efficient in conjunction with high explosives, affords any safeguard against explosions arising from the presence of fire-damp or of coal-dust associated with fire-damp, in mine workings where blasting is carried on, if *powder*, or any explosive agent analogous in its composition and mode of explosion to powder, be employed in conjunction with them.

"Suggestions have been made to use, in conjunction with *powder*, or as tamping over the charge, certain solid preparations which will evolve gases or vapours when exposed for a sufficient period to heat capable of extinguishing flame, the idea being that the heat developed by the explosion of the charge would accomplish the desired results, and that the dangers arising from blown-out shot might thus be guarded against."*

Exploding Charges in Fiery Mines. —*Lieutenant-Colonel T. Lauer*, of the Austrian Imperial Engineers, has invented a very ingenious as well as simple method of firing powder, dynamite, or other explosives, which is specially adapted for use in fiery mines. He lays down five rules relating to blasting in coal-mines which miners would do well to bear in mind, as they refer to the prevention of fire-damp explosions by the charge, often a fruitful cause of explosion.

The rules in question are :—(1) No charge should be exploded before it has been ascertained by means of the safety lamp that within a radius of 30 ft. the quantity of fire-damp is less than 3 per cent. (2) The firing of the charges by ordinary fuzes or squibs should be absolutely forbidden, as the combustion of these causes an inflammation of the fire-damp. Only electric or other similar methods of firing should, in fact, be permitted at all. By the use of these methods sparks are produced only in the interior of the bore-hole charge. (3) Simultaneous firing of the bore-hole charges should be brought into use, for if the charges are fired in rotation those first exploded will not only produce coal-dust, but will sometimes open seams from which fire-damp escapes, and is fired by explosions following after. (4) The use of ordinary gunpowder and its derivatives should be forbidden, and only strong high explosives should be used. (5) A sufficient amount only of explosive should be taken in order to make a charge to cause dislocation and rending of the surrounding coal and rock, in which case a

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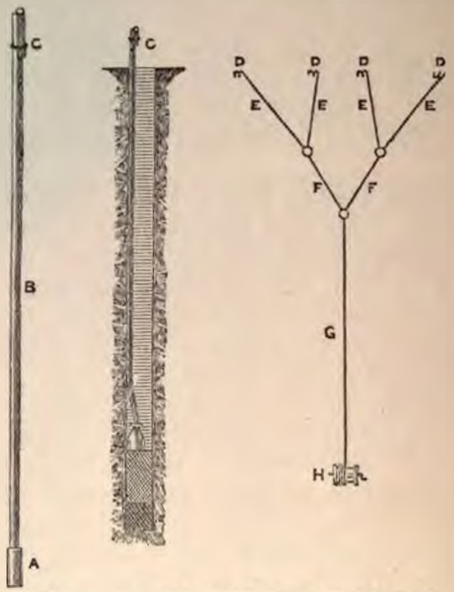
* In a previous chapter (p. 121) I have described a solid tamping mixture which has been invented by Mr. Trench, and which is now being introduced in lieu of the water cartridge. From the testimony of several colliery proprietors it would appear that this tamping mixture possesses the property of rendering tonite flameless when exploded in cartridges surrounded by the mixture.—M. E.

consumption of the explosive takes place inside the medium in which it is employed and no flame escapes.

In the use of the detonating friction tube, which has been invented by Col. Lauer, the spark (as with the electric exploders) is caused inside the body of the explosive in the bore-hole, and, as several charges can be fired simultaneously, the system appears to commend itself by its cheapness and simplicity.



FIGS. 95, 96, 97.—LAUER'S SYSTEM OF FIRING CHARGES.

The friction tube in this apparatus consists of a small cylinder, A, Fig. 95, which encloses the friction apparatus, and this is connected with an iron wire, C. The iron wire as well as its protecting tube, B, are long enough to extend a few inches beyond the mouth of the bore-hole (see Fig. 96), and the wire terminates there in a loop, C, which for safety is bent over and fastened to the tube by a string. The fulminating cap and primer are set in the bottom part of the small cylinder, A. The bore-hole is charged in the usual way. To fire the mine, the loop, C, is untied from the tube, B, straightened out and tied to a strong string of a certain length, which ought to enable the miner to get beyond the radius of projection from any flying *débris*. By giving a smart pull to the end of the cord, the iron wire, C, becomes disconnected from the friction apparatus and causes the inflammation of the composition contained in the small cylinder, A, and the detonation of the exploder and charge.

For the simultaneous firing of several charges, all that is required to be done is to connect together the strings, E and F from the several bore-holes to one main cord, H (Fig. 58). Each string, E, ends in a kind of hook, D, which is tied to the loop, C. The main cord, G (Fig. 97), can be laid on pulleys fastened to the sides of the tunnel or drift, so as to keep the same in line. All the mines being connected, the small winch, H, is first put gently in motion so as to give a certain amount of tension to all the strings, then a strong pull is given to the cord, G, which will cause the simultaneous explosion of all the charges.

It is claimed that eight charges can be fired in this manner. This system of firing has been tried in several Austrian coal-mines, and seems to have given satisfactory results.

Compressed Lime Cartridges.—The considerable increase in volume which caustic or quick-lime rapidly undergoes during the slaking process, or its conversion into hydrate of lime by union with water, was many years ago regarded as a source of power which might be made available in lieu of powder for the bringing down of hard coal.

Messrs. Smith & Moore prepare the lime for this purpose by reducing freshly burned fat lime of high slaking power to powder, and converting this into cylinders by applying powerful pressure, which produces a very compact cartridge, rendering the material less liable to deterioration from air slaking than if kept in lumps. In the next place, they apply the heat which will have been rapidly developed in the loaded hole by the slaking of the lime charge simultaneously throughout its entire length, to the generation and superheating of steam on a somewhat considerable scale, whereby the force exerted by the expanding charge of lime is supplemented in an important manner. This is effected by ensuring the application of water to the compressed lime almost simultaneously throughout the entire length of the charge.

Sir Frederick Abel, in commenting on the use of lime cartridges, states that, during a series of operations in the Shipley collieries, Derby, the preparation and charging of a number of holes at one time was expeditiously carried out, and the joint action of the holes in bringing the coal down in large masses was very satisfactory, the charges generally performing their work up to the back of the holes. The time occupied by the action of the lime ranged from ten to forty minutes from the time of wetting the charge, but the men were able to return to their work directly the coal had fallen; the latter was brought down almost entirely in large masses, and the work in such coal appeared to be carried on with advantage in point of economy over blasting. The results obtained with lime cartridges in other collieries seem to be satisfactory on the whole. That its application should not be attended with the same success in soft and in very hard coal as in massive coal of medium hardness is to be expected, and seams in which many fissures occur are not likely to be worked successfully by the system, as the force due to the generation of steam by the slaking of the lime must be lost in many instances.

In damp mines, the cartridges should be kept in tightly closed cases until just before they are required to charge a hole with.

A so-called blown-out shot with lime causes the latter to be more or less violently scattered about in the vicinity of the shot-hole, and should men be in the immediate neighbourhood it is very possible that their eyes may suffer from such an accident, but there is no possibility of an explosion being brought about by the blowing out of the lime, or by any other circumstance which may attend the use of the lime-cartridge.

The maximum heat developed in the interior of a lime-cartridge as applied in coal getting does not exceed 600° F., and is therefore insufficient to inflame a mixture of gas and air, or to ignite any inflammable material with which the lime-cartridge might possibly come into contact in actual practice.

The conclusion of the Royal Commissioners for inquiring into accidents in coal mines, that "in some coal-seams the lime-cartridge will perform work quite equal to that accomplished with powder, at no greater cost, and with absolute immunity from risk of explosions," was arrived at after very careful inquiry, and is well worthy of the attention of colliery managers.

CHAPTER XVIII.

APPLICATION OF EXPLOSIVES IN SUBMARINE ENGINEERING.

Removal of Obstacles in Rivers and Harbours—Methods of Submarine Blasting—Pontoon Drilling—Machine Drills—Drilling and Blasting—Blowing up Sunken Wrecks.

It becomes very often the duty of an engineer, in making river or harbour improvements, to remove loose rocks, boulders, logs, sunken ships, which form obstacles to navigation, and in such cases the application of surface charges of dynamite, properly located against the object, will effect the purpose. In such blasts it is usual when not using nitro-gelatine, to enclose the ordinary dynamite in tin tubes, which are fastened to long sticks and lowered from a boat against the object to be removed.

The firing in such cases is performed advantageously by electricity. In deep water divers have to descend to the river bottoms to apply the charges properly. The effect is usually very satisfactory, as the superincumbent weight of the water forms an excellent tamping.

When the rock-masses are large, holes have to be bored, which heretofore was accomplished by dropping heavy steel drills on to the rock and boring the holes by simple gravitation, but since the introduction of compressed air drills the drilling is accomplished by mounting these drills on platforms erected in the water or by mooring scows over the rock to be removed, and drilling from a platform projecting from the boat. These drills need the constant attention of divers, who also have to do the charging of the holes.

Submarine excavation is always costly and laborious work, and particularly so when submerged reefs are covered with strata of sand, gravel, and silt. Many ingenious inventions have been made to overcome these difficulties, and full information on this subject will be found in my work on 'Modern High Explosives.' As examples of modern engineering, detailed accounts of the removal of the obstruction in New York Harbour known as Hell Gate, and of the removal of obstructions in rivers and harbours in different parts of the globe, are given in that volume.

Methods of Submarine Blasting.—Before the invention of nitro-glycerine, the removal of rocks under water was considered one of the most difficult branches in engineering. The method first used was to place ordinary gunpowder in strong wooden cases, which were lowered on to the rock and exploded by ordinary fuzes. The application of these surface charges did not result in much work, and a French engineer, about thirty years ago, executed some work in Boston harbour, U. S. A., by drilling holes into Tower and Carwin Rocks,* by means of heavy bars of iron, weighing several hundred pounds, which worked in guides resting on tripods under water. The drill by means of a long rope is attached to a crank pin, and by means of an engine is hoisted several feet and then dropped; as many as sixty blows per minute are given in this way, and the gravitation of the drill bores the hole slowly. When this reached a certain depth, it was loaded by divers with a chlorate of potash compound and exploded.

At the present time such work is executed by machine drills, which are worked either from floating pontoons or stationary stagings erected in the water over the rock which is to be blasted.

The drill can also be mounted on a tripod stand, lowered on to the rock under water, and attended by a diver; drilling operations are carried on by leading compressed air to the drills by means of indiarubber tubing, and the exhaust di-

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* See 'Modern High Explosives,' p. 330.

charged through another tube above water. Then there are also instances where subaqueous drilling has been carried out in diving bells; but these are tedious and expensive methods. Of late also, at Port Natal, some important work was carried out by working from a tripod direct at the rocky bottom of the bay.

Pontoon Drilling is in favour with some engineers, by working long drills from the deck of a pontoon stage, so as to admit of the machinery being all above water and easy of access. It is usual to build a floating stage composed of two pontoon punts, secured parallel to each other several feet apart, thus leaving sufficient space for the working of the drills. On each side of the drills rails are laid, bearing two light travelling derricks, in each of which a guide-pole, 6 inches square, works freely, carrying on it a rock drill, and fitted with a rack and pinion gear for adjustment of the drill to the various depths required. The guide-poles are shod with iron, and, when in use, rest on the river bottom, the stage rising and falling freely according to the state of the tide or the swell caused by waves, without in any way affecting the steadiness of the guide-poles. The stage is secured against lateral movement by strong mooring-chains from each of the four corners, and worked by crab-winches.

One of the pontoons carries the machinery, such as the boiler, air-compressor, and air-receiver. The other pontoon is generally fitted as a workshop, forge, and a small air-compressor to furnish air to the diver, as it is advisable to supply the divers with air from a separate compressor or receiver.

I have had occasion to visit works of this description in the United States, and the plan usually adopted there is to erect over the rock to be blasted a stationary framing 20 to 30 ft. square, which is built of timber, and is easily dismounted, and the drills are mounted on this staging; they are worked by steam. The boiler is on a scow, which at the same time carries the dredger, and as the drills are worked by steam which is led to them in tubing, no air-compressor is required, except a small one to supply the divers.

I have also seen a small stage from which two drills are worked, consisting of a large box made of 1½ in. planks, 12 ft. square and 3 ft. high, air and water tight; this box was mounted within four posts, and when the holes were to be fired, by turning a crank, working a rack and pinion gear, the box was lowered on to the surface of the water and the four posts lifted out of position, so that the same became a floating stage, and could be moored back again after the firing of the blasts.

Where the stationary stagings are large, 20 ft. square or more, the blasting can be carried out safely, without damaging the supports, and they are only shifted whenever the bore-holes become located too near the supporting posts.

Machine Drills.—The drills are generally of a heavy pattern, at least 5 in. diameter by 8 in. stroke, and the drill steel ranges from 2 to 3 in. diameter, as long bars have to be used when there is any depth of water.

Each drill works in a sliding frame, so that several feet in depth can be drilled without adding on fresh length of steel to the drill, or changing to longer bars. Sometimes the depth of water over the rock may be 20 ft., and as the drill platform is several feet above the water surface, and holes have to be bored 6 to 7 ft. in depth, it is not unusual to have drill steel 35 ft. in length.

In case the rocks which have to be removed are covered with mud, silt, gravel, the boring becomes very difficult, as the silt will work in between the drill and the sides of the bore-hole, and jam the drill. To avoid this inconvenience it is a usual practice first to drive down iron tubes through the silt 4 to 5 in. in diameter till they rest on the rocks, and then the drills are worked within them. These tubes reach above the surface of the water and prevent the sand getting into the bore-holes, and also enable the workmen to let the cartridges into them from above, by tying them to a string, and thus dispense with the services of the diver.

General Newton constructed a scow in New York, f
carrying out blasting work in East River, which had a cent

opening like a well, into which he lowered a dome built of boiler iron, and there were several tubes inside these wells, in which he worked the drills.

Drilling and Blasting.—The bore-holes are drilled in rows located in a line across the river, or at right angles to the axis of the river. The depth of the holes depends on the depth of rock to be removed. When a hole is drilled, it is cleaned out by the diver, who inserts a nozzle into the hole and injects compressed air, to clean out the sand, and then plugs up the hole till the time comes to insert the charge.

If it is required to remove 6 ft. in depth of rock, it will be necessary to drill the holes 8 ft. deep, so as to get the explosive below the level from where the rock has to be removed, as otherwise there would be danger that if the holes were not bottomed the required depth would not be attained. To make sure of a successful removal, the holes ought never to be drilled too far apart.

When a row of holes are drilled, they are charged with the highest grade explosives, and powerful high-tension fuzes must be employed, and the holes being electrically connected among themselves, the leading and return wires are attached to the end holes; when the diver gets to the surface, connection is made with the battery and the charges exploded. Of course no tamping is required. When using dynamite, tin canisters are necessary to hold the charges, but with nitro-gelatine this is not necessary.

The explosion of the charges causes only a dull muffled sound and a slight upheaval, as the work is mostly expended in rending the rock and overcoming the resistance of the superincumbent weight of water, and very seldom rocks are projected above the water surface. The big pieces of rocks are afterwards removed by means of a derrick placed on the scow or the pontoons.

When a new hole is started it is very difficult to steady the lower end of the drill and make it enter the rock, and for this reason cast-iron shells weighing 100 lb. are used to steady them. This shell is about 1 ft. in height, 15 in. in diameter at the base, standing on three pivots or legs, about 3 in. long, convex on top, through the centre of which a hole passes vertically admitting the free working of the drill.

It is considered good work when 1 ft. can be drilled in half an hour, but the drilling of course depends on the nature of the rock.

Mr. Saunders,* of New York, has invented an arrangement which facilitates the working of drills on rocks covered with silt.

Works of magnitude, like the blowing up of Hallett's Points and Flood Rock at Hell Gate, New York, involved operations of a different nature. There the rocks were undermined by tunnels and galleries miles in length, the pillars which were left standing to support the roofs were drilled with holes, as well as the roofs, and when charged were all exploded simultaneously.

General Newton, the chief of engineers of the United States Army, has accomplished, in the laying out and prosecution of this memorable work, an amount of ingenuity which has no parallel in the history of explosive engineering undertakings.

Blowing up Sunken Wrecks.—Very often explosives are employed to remove ships which have got wrecked in the pathway of navigation. Divers who make this a special business then examine the position of the vessel, and by the application of long charges of dynamite or gun-cotton will break up the vessel. The charges are either placed on deck, or hung against the sides, or posts are driven into the sand and the charges tied to them. Care must be taken in all cases to have the explosive in immediate contact with the object to be destroyed, so as to obtain the maximum effect.

No special rules can be laid down how to proceed in such work, as each individual case presents features of its own, and has to be dealt with accordingly.

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* See 'Modern High Explosives.'

CHAPTER XIX.

APPLICATION OF EXPLOSIVES FOR MILITARY PURPOSES.

MODERN Explosives as applied in Warfare—Zalinsky's Pneumatic Gun—Essential Conditions of Dynamite Firing—How Zalinsky's Gun was Invented—Official Report upon the Gun—The German and the Maxim Pneumatic Guns—The Graydon Dynamite Shell—Gun-cotton Shells.

THAT modern explosives should have an extensive application for military purposes as a destructive agent is a development of their utility which one would expect to find. Our knowledge of these numerous compounds has received large contributions through the searching inquiries and experiments instituted by various Governments as to the qualities, both chemical and physical, of modern explosives, and the results may be thus summarised: The navy departments of most nations have adopted compressed gun-cotton for torpedo charges, and other submarine ground mines; whereas the military engineers of the land forces lean towards the use of the plastic nitro-gelatine and its derivatives as demolition charges, owing to their enormous shattering power (*brisance*) when bridges, stockades, railway embankments, walls, forts, and similar obstacles have to be removed. Such explosives as nitro-gelatine, gelatine-dynamite, and forcite, being far more powerful and exerting a greater local action than gun-cotton, should be able to rival the latter in its application to submarine mining; but so far as safety is concerned, wet gun-cotton, no doubt, offers an advantage which nitro-glycerine preparations do not possess. As bursting charges for shells and hollow projectiles, modern explosives will doubtless be extensively applied in the near future, and in that shape will form a terribly destructive engine of war. Their efficiency for that purpose has indeed been proved in the firing of projectiles from the weapon I am about to describe.

Zalinsky's Pneumatic Gun.—Lieutenant Zalinsky, of the United States Army, has practically demonstrated that large quantities of explosives, like dynamite, nitro-gelatine, or gun-cotton, even in charges of several hundred pounds, when enclosed in metallic shells, can be safely fired by means of compressed air.

I was present in New York Harbour in 1884, when the Lieutenant fired his first experimental shots from his four-inch gun at Fort Lafayette, and was greatly impressed with this modern weapon, although in military, naval, and scientific circles many authorities did not believe in the ultimate success of the young and energetic Lieutenant's so-called "Dynamite Gun." That he has triumphed by perseverance is proven by the fact, that the United States Government has constructed a cruiser equipped with these guns. I also understand that the Italian Government has ordered one from New York; and I may mention here that I brought this gun to their notice in 1886 by submitting the specifications and drawings to Admiral Martinez at La Spezia, and explaining to him the *modus operandi* of the apparatus.

Essential Conditions of Dynamite Firing.—Before entering into a description of the latest form of gun and projectile, it will be well to state the conditions which must be fulfilled to make dynamite firing successful.

The great requisite is, to discharge the dynamite shell from the gun without shock. Compressed air is eminently adapted to effect this in a perfect manner, as the pressure admitted to the gun can be regulated to any degree. Therefore, when firing the projectile, a gentle pressure is admitted, at first just sufficient to overcome its friction and inertia; but, once in motion, the pressure can be rapidly increased up to the full limit, without in any way subjecting the projectile to an undue shock.

Compressed air, also, permits the use of a detonator to explode the charge, and a strong exploder is embedded in the body of the charge, the explosion of which is caused by a specially designed electrical arrangement, which insures the perfect explosion of the dynamite in the shell. The detonator consists of a substance which is even more sensitive to shock than the explosive itself, and which by its sudden and violent action influences the latter so that it explodes with its maximum power.

Heating of the gun never takes place, as it is well known that compressed air when expanded absorbs heat and cools the surrounding atmosphere; hence this gun, instead of becoming heated by successive discharges, is actually cooled.

How Zalinsky's Gun was Invented.—The idea of firing dynamite by means of compressed air originated with a schoolmaster, named Meford, whom one of his pupils hit in the eye with a paper ball from his pop-gun. Being of an inventive turn, Meford concluded that compressed air could be used as a motive power for firing something else besides paper. He devised a tube of brass 2 in. diameter and ¼ in. thick, 28 ft. long, mounted on a **T** rail and stiffened with tie-rods; this was erected on a tripod, and arranged as a breech-loader. The slide block was attached to a flexible hose and connected to an air reservoir, from which the air was admitted by a hand-cock. This was very uncertain, the air being cut off too soon or else wasted by too long a delivery. The pressure was but 300 lbs. The projectiles used were cylindrical brass tubes 1 in. to 1½ in. in diameter, and 12 in. to 18 in. long; they had attached to them a wooden frustum of a cone, of which the larger end was the size of the bore. The point of the shell was of wood, and was loaded with lead so as to keep the centre of gravity well forward. Two discs of pasteboard, with a thickness of Canton flannel between them, acted as a gas check, the flannel being 1 in. larger in diameter than the pasteboard; this was placed against the under tail of the projectile.

The great difficulty was the short range attainable by these means; but, Lieutenant Zalinsky's attention having been called to this gun, he had it brought to his station and commenced experiments. He found an increased accuracy of aim over the ordinary smooth bores. The length in calibres of the 28 ft. gun was 168, and to this proportion is due the property of imparting great energy to a shell, and at the same time of avoiding a shock liable to produce premature explosion. With the 2 in. gun and a less pressure than 500 lbs., he had thrown a projectile across the Narrows of New York Harbour, a distance of 2100 yards.

In testing the safety of throwing dynamite in such thin shells, various experiments were tried. The dynamite in small quantities was placed at the base of the shell, and the balance was filled with dry sand; in this way it was exposed first to the shock from the air pressure, and next to that of the inertia pressure of the sand, which was much greater than that of an equal amount of dynamite. The pressure was gradually increased from 100 lb. to 500 lbs., and the shell was placed at 5 ft., 3 ft., 2 ft., and 1 ft. respectively from the breech, and finally a shell with the full charge of dynamite was thrown: placed at the breech, in this case, there was an air cushion of 8 ft. between the valve and the projectile. This 500 lbs. pressure being the limit of the endurance of the hose, a greater one was not tried.

The next series of experiments started with the construction of a gun 4 in. in diameter and 40 ft. in length. The barrel was a seamless tube of $\frac{3}{16}$ in. thickness, and in three sections, mounted on an iron truss supported by a tripod. The valve was automatic, opening rapidly and permitting a certain uniform volume of air to escape, and closing at the time the projectile reached the muzzle. Its general character may be described as that of a balanced valve. The air was admitted by this until the projectile was just outside the muzzle, and, to have the final pressure as great as possible, the reservoir was nine times the volume of the bore. The velocity attained with the 4 in. gun was found to be 72 per cent. of the theoretical velocity.

In early experiments with the projectile, the tails were found to be too long and heavy, and the best results were attained by making the centre of gravity as near to the point as possible. The projectile being assumed to fall the instant it left the gun, it was decided to have the rear of the tail taper slightly to afford freedom of exit, and such projectiles had regular flights. The pressures being uniform, the fall of shells having the same centres of gravity struck nearly in the same places. In fact, accuracy of range with a pneumatic gun is one of its strongest features.

The shells were next fired with 17 lbs. of dynamite and with success. The fuzes then met the attention of this investigator. The ordinary percussion fuzes of fulminate proved unsatisfactory, as did the copper capsules. It was also noticed that 17 lbs. shells with percussion capsules did not produce the desired effect when they exploded, and Lieutenant Zalinsky naturally looked to a possible effect from exploding these shells from the rear, assuming that a small interval of time was required even to fully explode dynamite, and that the layers of gases exploded near the target tended to retard the effect of those developed at the rear of the shell.

This resulted in the devising of an electric fuze depending on the action of a small battery enclosed within the shell. The best battery was found to be the chloride of silver one, on account of its small size and its reliability. After remaining idle a month, these little batteries were found equal to the requirements. The diagram, Fig. 98, is a section of the fuze and connections, in which A is the fuze case, B a metallic plunger, inside the vulcanite cylinder *a*; the contact springs *b b* are attached to the wire *c*, joining the electrical primer C. The second wire *d* goes from the primer to the metallic fuze case. The primer is thus in contact with one pole of the battery placed within the upper part of the fuze case. As will be seen, this battery is suspended to the fuze case A A by thin projections *e e*, which are sheared off by the shock of firing the gun, and the other pole falls into such a position that the metallic plunger B can come into contact with it and complete the circuit. When the shell strikes, the plunger B moves forward to the pole *f*, the circuit is closed and the charge is exploded.

By examining the diagram, Fig. 99, it will be seen that in the fuze just mentioned the battery was attached to a projecting steel plunger held in place by a stiff steel wire pin, and when the end of the plunger is within $\frac{1}{8}$ in. of the target the circuit was closed. In this diagram, A is the steel plunger and B the battery attached to it; C is a low-tension electrical primer, one wire from which, *c*, goes to a contact *b* in the bottom of the fuze; the other, *c'*, connects the primer and the fuse case. On striking the target the plunger is forced in, shearing off the light steel safety pin, and when the front of the shell is at the desired distance from the target the pole *a* of the battery comes in contact with *b*, and the circuit is closed through the primer, which explodes the charge from the rear. The actual time required to produce explosion before the full impact of the shell took place, is $\frac{1}{10000}$ of a second. Plungers arranged to close up to $\frac{1}{4}$ in. from the target were successful, but beyond that the effects were weakened. Ex-

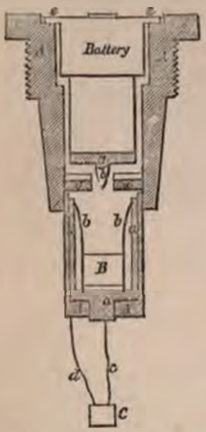

FIG. 98.—EXPLODER FOR PNEUMATIC DYNAMITE GUN.

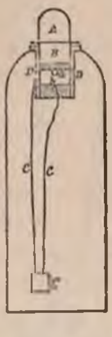

FIG. 99.—SHELL WITH EXPLODER.

periments showed that it was important to bring the charge as intimately in contact with the target as was possible with as large an area of contact as possible.

The next step in this investigation was the construction of an 8 in. gun, designed to throw 100 lb. of dynamite with an initial velocity of 1400 ft. per second, and with a range of two miles, and to have it so arranged that the gunner could aim, elevate, and fire it without removing his eye from the sight. A view of this gun is given in Fig. 100. The pressure to be used was 2000 lbs., and the length of the gun was 60 ft. The 8 in. gun when worked with 1000 lb. pressure, and at an elevation of 35 deg., a shell with 60 lbs. of explosive material has been thrown $2\frac{1}{4}$ miles, and one with 100 lbs., at an elevation of 33 deg., was thrown 3000 yards.

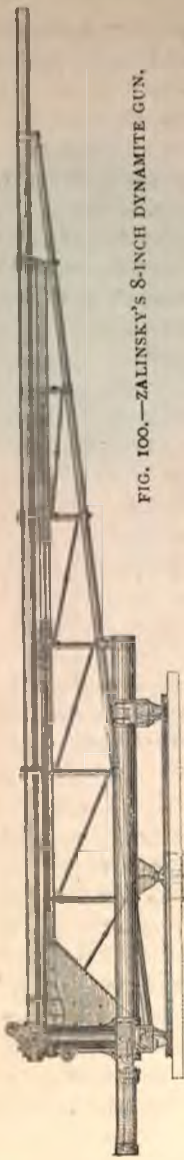

FIG. 100.—ZALINSKY'S 8-INCH DYNAMITE GUN.

Official Report upon the Gun.—Under the direction of the authorities of the United States Navy, an official inquiry into the merits of Lieutenant Zalinsky's weapon has been held, and the Board to whom the inquiry was entrusted, having witnessed experiments to test the rapidity of fire, accuracy, and extreme range of the new gun, have reported as follows:—

"1. That the dynamite gun is a new instrument which has its own functions in time of war; that it cannot replace any existing weapon; and that its place cannot be wholly taken by any other.

"2. That the value of compressed air as a means of throwing projectiles from a gun is chiefly apparent in the ability which it gives to the gunner of exactly reproducing any shot, and of accurately increasing or decreasing range, at will.

"3. That the machinery employed in connection with the control of air under great pressure is very effective.

"4. That the gun is remarkably accurate.

"5. That the extreme range is probably about two miles, the effective range from 1400 to 1800 yards.

"6. That the power of the projectile has not yet been thoroughly tested.

"7. That the gun appears to be trustworthy in its action.

"8. That the system is a simple and inexpensive one, and that the gun might be made in any large town where there are foundries and machine shops.

"9. That the weapon is valuable for harbour defence.

"10. That it is adapted to naval warfare whenever mortar fire can be advantageously used.

"11. That a modification of it might be adapted to the projection of torpedoes from ships.

"12. That, until after the gun has been properly tested on board the dynamite cruiser which is now under construction, it will be inexpedient to adopt it as part of the battery of ships of war."

The dynamite cruiser which is referred to in the report was built by Messrs. Cramp, of Philadelphia, and has now been successfully launched. Instead of the 10·5 in. pneumatic guns for which she was originally designed, she is to have three 15 in. tubes, which will be able to throw shells loaded with 600 lbs. of explosive gelatine. The length of her guns, which was excessive, has also been shortened to 55 ft. The gun which has been constructed for the Italian Government has a calibre of 15 in., and a length of only 40 ft.

The German and the Maxim Pneumatic Guns.—Another pneumatic gun has, according to the *Temps*, been tried this year in Germany, under the supervision of the German Admiralty. The instrument is of 11·7 in. calibre, and is 73·8 ft. long. The shell was 81·5 in. long, and contained 66 lbs. of nitro-glycerine. The target was a wooden vessel moored 2080 yards away from the firing-point. Two rounds of shell completely destroyed the craft.

Of Mr. Hiram Maxim's dynamite gun little of a practical nature is yet known. It is a pneumatic tube; but the tube is comparatively short, and, according to the specification of the patent, a very high muzzle velocity is attained. The peculiarity of the invention seems to consist chiefly in the substitution of a mixture of air and some volatile hydrocarbon for air alone. This mixture is so regulated that there shall be just sufficient oxygen to convert the hydrogen of the hydro-carbon into water, and the carbon into carbonic acid gas.

After the projectile has been driven by the expansive force of the gas through a certain portion of the length of the bore, the mixture of air and hydrocarbon is caused to explode, and the pressure is thereby at once increased about eight-fold. The explosive charge in the shell is to be some form of dynamite, detonated by means of a capsule and firing-pin. It does not, however, appear that Mr. Maxim has yet built a gun in accordance with his designs.

The Graydon Dynamite Shell.—*Graydonite* is the name which has been given to an invention of Lieutenant James Weir Graydon, late of the United States Navy, who in 1886–87 conducted, first in California and afterwards in Russia, a series of experiments with the Graydon dynamite shell. This he succeeded in firing, with some degree of success, from a 6 in. rifled gun that was loaded with a mixture of 1 lb. of dynamite to 37 lbs. of powder. Mr. Graydon claims for graydonite absolute freedom from danger in handling and transportation, a destructive power from 400 to 700 per cent. greater than that of No. 1 dynamite, and suitability for military and naval uses. Particulars of its composition have not been made public. Since the conclusion of the experiments in Russia, the Ordnance Board of the United States Army has assisted at further experiments with the Graydon dynamite shell at Sandy Hook.

The Graydon method of charging the shell consists in sub-*dividing* the bursting charge of dynamite into small pellets, each of which is enclosed in a separate envelope and treated with paraffin. The interior of the shell is previously lined with asbestos. Explosion is secured by means of a detonator, which acts upon impact. The great advantage of the shell is alleged to be that it can be fired from any service gun with the ordinary service charge of powder.

At the Sandy Hook experiments a 7 in. Ames wrought-iron muzzle-loading rifled gun was used, with a powder charge of 23 lbs., and with a steel service shell that weighed, with its charge of 2·3 lbs. of No. 2 dynamite, about 122 lbs. The target was a section of wrought-iron turret, made up of two 7 in. plates, so as to give a total thickness of 14 in. The target was, however, not a new one. It had been indented by previous practice, and several cracks in its surface were noticeable. Three shells were fired at, and burst on, the surface of this target. The third round penetrated the first plate, seriously bulged and cracked the second, and had a generally disruptive effect upon the turret.

The next day four rounds were fired, two at a wooden target a mile away and two seaward. All the shells were fused. The first shell burst prematurely 300 yards from the gun, the second burst at or beyond the object, the third did not burst, the fourth burst prematurely at 1000 yards. These results were not satisfactory. Later in the day the liability or otherwise of the dynamite to explode on being fired into with small-arm projectiles was tested. This experiment was also unsatisfactory. The compound exploded on being struck at 50 yards by a Springfield rifle bullet. Yet it was something to have shown that the dynamite shells could be successfully fired from an ordinary gun, and were capable of inflicting serious damage upon a somewhat heavily-armoured target.

Gun-cotton Shells.—The following extracts from an article upon this subject—translated from a German publication*—will be read with interest :—

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* *Schweizerische Zeitschrift für Artillerie und Genie*, December, 1887. For the translation I am indebted to *Engineering* of 15th June, 1888.

"The German artillery, in opposition to the French, decided against melinite in favour of gun-cotton as a burster for shells, a substance already adopted by the German Navy for projectiles of large calibre and torpedoes. These shell fulfil the object of perforating in the shortest time and with absolute certainty the projection given in the opposing forts, of acting as mines in the cavities formed, and of rendering the occupation of the structure assailed absolutely impossible. It is no longer a secret that during last autumn and winter the 15 cm. and the short 21 cm. German guns, fired at Kummersdorf with high bursting charges of gun-cotton, succeeded in perforating the defence of forts, which were specially constructed so as to represent one of the French frontier forts, and in reaching the parts best covered, such as the magazines, &c., with overwhelming effect—a notable and important triumph for the German artillery.

"Artillerists have studied the properties of gun-cotton for a long time. Ten years ago it was experimented with at the Government gun-cotton factory at Hanau under the direction of an officer of the German staff, and in the end the disadvantages in its use were overcome, and it was produced in a form which places it in the first rank as an explosive for shells, damp cotton specially prepared being now used for that purpose. It is carried on service in a moist state, and to explode it a primer of dry cotton with a special detonating composition is employed. The construction of this primer is kept secret. The damp state of the cotton gives security against premature or spontaneous explosion, tendencies which were rightly considered defects in the use of the earlier forms of gun-cotton.

"The great safety in transport and use of gun-cotton now obtained is due not only to the experiments at Hanau, but also to others made by the firm of Von Förster and Wolff at Walsrode, in Hanover, who, in 1883, took out two patents, one for a mode of preserving gun-cotton, the other for the construction of a shell fitted with that substance.

"Von Förster's method of preserving gun-cotton consists in dipping the cotton either in a dry or moist state into ether for

15 to 20 seconds, whereby a very thin, hard, yellowish-brown film is formed on the surface of the cotton, rendering it waterproof, and giving it the semblance of a piece of wood. Instead of ether, nitro-benzol, or any fluid which dissolves the cotton, can be used. This film in no way decreases the explosive qualities of the gun-cotton, but it prevents its losing its consistency and decomposing. It preserves the requisite degree of moisture, and prevents paraffin soaking in. As, however, the skin is not absolutely impermeable, water finds a passage and the cotton is modified by keeping. Von Förster, however, states that under favourable conditions this disadvantage can be neglected, as experience has shown that gun-cotton unprovided with a protecting film loses its moisture in a few days if exposed to a current of dry air, whereas the protected cotton retains its moisture for many weeks under the same conditions. On the other hand, the skin is so slight that it does not interfere with the rapidity of ignition.

"In case dry cotton charges should be preferred, Von Förster recommends dipping them in ether, closing the channel for ignition by means of a paper washer, and giving the charge a bath of paraffin, which adds a second impervious lacquer.

"Von Förster, it should be added, disapproves of the use of gun-cotton impregnated with paraffin, as prepared in the Kruppamühle factory in Schleswich. This, he states, is secure neither against decomposition nor accidental ignition; it is as liable to explosion as dry cotton; and is more sensitive to concussion than the wet cotton, being exploded by three successive rifle bullets, which would have no effect on gun-cotton containing 15 per cent. of moisture.

"The projectile, which forms the subject of the second patent, is a cast-iron shell in two parts screwed together and filled with discs of compressed gun-cotton. Towards the base of the shell a detonator is placed, connected by a channel with the gun-cotton placed above it. The shell is fitted with a common percussion fuse, which communicates with the detonator by a primer, either of granular gun-cotton or the same substance mixed with meal powder. The patent does not specify how the detonator is fixed in position. This arrangement was chosen after experiments made with gun-cotton exploding in the open air, and the following results were also determined. The force of gun-cotton varies with its density. It is more powerful in a moist state than when dry. It is best to ignite the charge as far as possible from the point of attack, and an axial channel through the charge increases the effect of explosion.

"It does not appear that these shell as described have been tried, and the most recent experiments with shell exploding in the open do not seem to confirm the conclusions as to the position of the detonator and the value of the axial channel. The endeavour was made to improve the shell by charging it through the fuse hole, leading to a further patent in May, 1885, for another mode of charging shell and of securing the explosive contents.

"The gun-cotton in this is used in the form of prismatic grains, made by cutting up the compressed discs, and to the charge of wet cotton 200 grms. of dry cotton are added. When the charge is placed in position the neck of the shell is closed by a plug, leaving space for the fuse and detonator, which is pierced by a curved channel through which paraffin at a temperature of 75° to 80° is poured. The paraffin fills all the interstices between the grains, and as it hardens forms the whole into a compact mass.

"The fuse is the same as the German percussion fuse, model 1873. The cupped part of this is lengthened and is open at the base, enclosing a capsule which contains 1 grm. of fulminate, surrounded by an india-rubber ring and washer. The whole is fixed by a screw. By slightly modifying the arrangement a delayed action fuse is obtained. To secure the immediate action of the capsule on the charge the former is surrounded with a primer of 10 grms. of dry gun-cotton, protected against concussion by an india-rubber ring. The shells are kept in store loaded, but the fulminate and fuse are only inserted when required for use.

"The German Government delivered in the spring of 1885 to the Walsrode works a cast-iron 15 cm. gun for trial of this mode of charging shell. Shells 2 and 2½ calibre were used, weighing with lead coat 27 kg. empty and with an internal capacity of about 2 dm.^{3} Each shell had a charge of 1·35 kg. gun-cotton, 20 per cent. moisture, in rectangular grains 10 mm. by 20 mm., with 200 grms. dry cotton in cubical grains of 6 mm. The powder charge was 1·5 kg., distance of butt 70 m., velocity of shot at 30 m. being 245 m. Of five rounds none burst prematurely, two were set for delayed action and formed larger cavities than the other three. The shell were shattered into very small pieces, none of which exceeded a few millimetres in size. A hail of small pieces was thrown back more than 70 m. A loaded shell was then embedded in the butt and exploded, producing a crater about 2 m. diameter, 70 cm. deep, and 1·25 m.^{3} in capacity.

"Von Förster thereupon adopted a new position for the capsule—of which he gives no information—but which seems to have given good results, and the trials were continued to test all the points in his system.

"For this purpose blind shell were fired with primers of wet cotton. The detonators were found unexploded. This was followed by loaded shell without primers or detonators. The charge of gun-cotton was found to be neither consolidated nor altered. Filled shell with primers were then fired against the butt strengthened with wood baulks and iron rails, but the shell failed to explode; the butt was still further strengthened sufficient to break up a blind shell on impact. Under these conditions the charged shell for the most part burst. In some cases, however, they rebounded uninjured.

"Finally, fully charged and fitted shells were used, more than 200 rounds of 8·8 cm. shell being fired with a velocity of 450 m., common shell filled with gun-cotton were fired with a velocity of 200 m. from the rifled 15 cm. mortar and from the 15 cm. gun with a velocity of 400 m. These guns fired also steel shell 6 calibres long fitted on the same system. No premature burst occurred, and the bursts were in all cases satisfactory.

"On exploding an 8·8 cm. 7 kg. cast-iron shell at rest, 200 pieces over 10 grms. and 600 under 10 grms. were counted. An 8·8 cm. steel shell, 6·64 kg. in weight, gave 23 large pieces weighing together 2·26 kg., and 127 weighing 2·865 kg. A cast-iron 15 cm. shell, weight 27 kg., gave 376 pieces over 10 grms., and 828 pieces under 10 grms. in weight were found to pass through wood baulks 25 cm. thick. A 15 cm. shell 6 calibres long, with a charge of 9·935 kg. gun-cotton, sunk vertically in the ground, the base 25 cm. beneath the surface, gave a crater 4 m. broad, 1·30 m. deep, and 7 $m.^3$ in capacity. With a burster of 16 kg. the following dimensions were obtained: 5·1 m. diameter, 1·56 m. depth, 12 $m.^3$ contents.

"In November, 1885, it was announced that the German Government had adopted the Walsrode gun-cotton for shell bursters.

"In 1882 the German artillery commenced experiments with shells filled with gun-cotton on its own account, the original experiments being to determine the possibility of using high bursting charges with the 21 cm. mortar. Steel was used for the shell instead of iron, so as to increase the strength of the walls and permit the employment of larger charges, and the length of the shell was carried to 5 calibres.

"The following is a description of the 21 cm. mine shell: The shell is formed in two parts screwed together. The gun-cotton is contained in a zinc case and consists of small discs of compressed cotton 5 mm. thick with 20 per cent. moisture. A primer of dry cotton is placed in the upper half of the shell, which is pierced by a central channel for the quicksilver detonator. When the burster is placed in its case a wooden tube is inserted in the channel for the detonator, and paraffin is poured in to fill the interstices. A metal plug then closes the case in which an opening is left for communication with the detonator. When the burster is in place the head of the shell is put on and a metal cylinder inserted which fixes the burster and receives the fuse and detonator.

"The use of compressed gun-cotton discs permits of the use of a charge about one-third heavier than when the gun-cotton is inserted in grains, but in the latter case making the shell in two parts can be avoided.

"General Brialmont states that in 1883 experiments were made with the 21 cm. mortar against casemates of strong brickwork 1 m. thick covered with 80 cm. concrete and 1 m. to 1·5 m. of earth. Shell 6 calibres long with 19 kg. of gun-cotton as a burster perforated the structure and burst inside. It was further observed that the 21 cm. shell, with a burster of 26 kg., fitted with delayed action fuse, penetrated 4 m. into sand. A casemate 1 m. thick, with 3 m. sand, would be perforated by such a projectile, which 5 m. of protection are required to keep out. The craters in the sand measured 4·80 m. in diameter, 2·4 m. deep, and were about 15 $m.^3$ in capacity.

"The trials were extended to shells for other natures of guns, especially the 15 cm. and 28 cm. mortars. The burster of the last is given as 50 kg."

APPENDICES.

Appendix A.—*CAPTAIN HESS ON THE ANALYSIS OF EXPLOSIVES.*

Appendix B.—*DETERMINATION OF STABILITY.—INSTRUCTIONS AS TO TESTS ISSUED BY THE HOME OFFICE.*

Appendix C.—*APPLICATIONS FOR AUTHORISATION OF EXPLOSIVES. — INSTRUCTIONS ISSUED BY THE HOME OFFICE.*

Appendix D.—*THE EXPLOSIVES ACT*, 1875.—*ABSTRACT OF THE PRINCIPAL PROVISIONS OF THE ACT.*

APPENDIX A.

ON THE ANALYSIS OF EXPLOSIVES.*

BY

PHILIP HESS,

Captain of Engineers in the Austrian Army.

Section I.—THE ANALYSIS OF NITRO-COMPOUNDS—Determination of Nitrogen in Gun-cotton and Glycerine—Results of Analyses by various methods—Analysis of Kieselguhr Dynamite—Of Explosive Gelatine—Of New Dynamite No. 1.

Section II.—COMPOSITION OF GUN-COTTON SAMPLES—Method of Analysis—Results of Analyses of Lenk's and Abel's Gun-cotton—Determination of Ash Residue of Gun-cotton.

Section III.—QUALITATIVE AND QUANTITATIVE CHEMICAL ANALYSIS OF NITRO-GLYCERINE COMPOUNDS—Ingredients of Nitro-glycerine Compounds—Qualitative Examination—Quantitative Examination—Notes as to Analysis of Nitro-gelatine containing Camphor.

I.—THE ANALYSIS OF NITRO-COMPOUNDS.

Determination of Nitrogen in Gun-cotton and Nitro-glycerine. — Champion and Pellet discovered a method for the determination of the nitrogen in gun-cotton,

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* Translated from the German, as published in 'Mittheilungen über Gegenstände des Artillerie und Genie Wesens,' Vienna.

which was based on the reaction; that on boiling nitro-cellulose with ferrous chloride and hydrochloric acid, all of the nitrogen of the nitrates is disengaged in the form of nitrogen oxide, and can be exactly measured.

A vacuum is created in the flask in which the reaction is to be carried on, by boiling a certain weight of gun-cotton with distilled water, and the ferrous chloride mixed with hydrochloric acid is introduced into this flask by aspiration; and when on heating the flask to boiling, the nitrogen oxide is developed, it is conducted into a graduated tube, where it is measured.

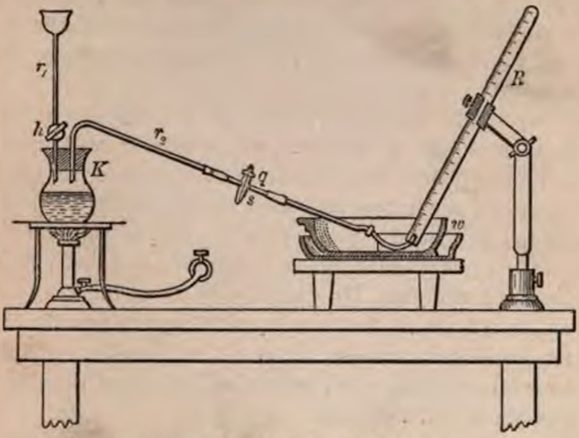

FIG. 101.—APPARATUS FOR ANALYSING.

F. M. Eder, who employed this method almost exclusively in his determination of nitrogen oxide in pyroxylin, introduced one modification, in that he substituted a solution of ferrous sulphate in hydrochloric acid for the ferrous chloride, and yet obtained equally satisfactory results.

[The apparatus used by Captain Hess is identical with the one used by Champion and Pellet, and is shown in Fig. 101.]

Twenty to twenty-five grams of crystallised ferrous sulphate are dissolved in 100 cubic centimetres of water, in a flask K holding from 150 to 200 c.c., and to the solution a few small scraps platinum are added to prevent bumping during the boiling. The flask is closed with an india-rubber stopper having two bores, through which the glass tubes r and r_2 are inserted. The tube r_1 is closed by the cock h, and r_2 is closed by means of the pinch-cock q fastened to the india-rubber connecting tube s.

Through continuous boiling all air is expelled from the flask, and the end of the tube r_2, which is bent up at nearly right angles, is introduced into the graduated tube R, which has been filled with caustic soda solution, and stands in the basin w, which also contains caustic soda solution, as shown in the figure.

An accurately weighed quantity of the nitro-compound is dissolved in about 5 to 6 c.c. of sulphuric acid, and the solution poured into the funnel of r. From 0·12 gram to 0·16 gram of the nitro-compound are generally weighed out. The funnel is washed down with 2 to 3 c.c. of sulphuric acid, which is first poured into the small beaker glass that contained the dissolved sample. By carefully opening the cock h, the acid solution flows in the flask K, whereby the introduction of any air bubbles is avoided as much as possible. Afterward the funnel is washed down with distilled water till the flask contains about 8 c.c. of fluid.

After heating the flask, a small pressure is obtained, the pinch-cock q is carefully opened and the nitrogen oxide with some steam is driven toward R. At the commencement only that gas is collected which is produced by the contact of the concentrated acid solution with the ferrous sulphate solution. The remainder of the nitrogenoxide is only disengaged by the concentration of the contents in the flask, which goes on gradually as the liquid boils down; and a very small quantity even remains behind and cannot be expelled in this way. When the contents of K commence to puff up, the tube r_2 is closed by q, the flame is extinguished and a vacuum is formed in K, and thereby the nitrogen oxide is disengaged, which was still retained by the liquid in K. After a while about

20 to 25 c.c. of water are introduced in the flask and the distillation is continued, whereby the remnant of nitrogen oxide is driven off with great facility toward R. The process can be considered as finished, when no further augmentation of the gas volume is noticed. The following table clearly shows how far the results, which have been obtained by various methods employed in the determination of nitrogen, agree.

To establish the correctness of the method, the following trials were made on—

1. Chemically pure nitromannite (recrystallised twice from alcohol).

2. A nitro-glycerine, the nitrogen contents of which have been determined by Dumas' method by Captain Dittel, and found to be 18·35 per cent.

Both these samples were analysed, and the correctness of the method established.

According to Champion and Pellet the composition of gun-cotton is pentanitro-cellulose, and the commercial nitro-glycerine in the dynamites is pretty nearly trinitrin.

The nitrohydro-cellulose, of the factory at Zamky, shows an unexceptionally low percentage of nitrogen, and it can be surmised that in its employment for primers for nitro-gelatine it could be advantageously replaced by higher nitrated gun-cotton.

The nitrogen contents of the collodion-cotton examined coincide exactly with the collodion-cotton prepared after Schering's method.

The paper powder prepared by the firm of Prentice and Co. was to a certain extent insoluble in sodium sulphide solution, so that it must have been a mixture of nitrated and unnitrated gun-cotton.

Kieselguhr Dynamite.—The simplest form of dynamite is the old Kieselguhr dynamite. For the analysis, from 1·5 to 2 grams (23·2 to 30·9 grains Troy) of this powder is put in a watch-glass of known weight, and dried in an exsiccator, over

RESULTS OF ANALYSES MADE BY VARIOUS METHODS FOR THE DETERMINATION OF NITROGEN IN CERTAIN NITRO-COMPOUNDS.

Preparation.	Percentage of Nitrogen as found by Method of				
	Dumas.	Crum-Hempel, modified by the employment of Lunges Nitrometer		Champion and Pellet.	Champion and Pellet modified.
		and rinsing down with concentrated Sulphuric Acid.	and rinsing down with dilute Sulphuric Acid.		
Nitro-mannite, recrystallised twice from Alcohol. Theory N=18·58%	..	18·33 18·43	18·52	..	18·53
Nitro-glycerine from Nobel's Kieselguhr Dynamite. Zamky, 1879 .	18·35	18·20 18·24 18·19	18·42 18·34 18·45	..	18·52 18·42 18·55
Collodion-cotton from Moll in Vienna	..	10·98 11·05 11·23	..	11·27	..
English Gun-Cotton from Waltham Abbey, 1874	..	12·67 12·56	..	..	..
English Gun Cotton from Tonite, manufactured at Faversham, England	..	12·92 12·86	..	..	13·02
Prussian Gun-Cotton from Kruppamühle, 1879	..	12·17 12·27 12·20 12·29	..	..	..
Hirtenberg Gun-Cotton, immersed for over ten years in water . . .	..	12·11 11·88	..	..	..
The same Hirtenberg Gun-Cotton, dried and nitrated again in a mixture of 1 part concentrated NHO_3 and 3 parts concentrated H_2SO_3 .	..	12·92 12·80 12·89	..	..	..
Nitro-Glycerine from Guhr Dynamite. Zamky, 1880	..	18·20 18·21	..	..	..
Nitro-Glycerine from Guhr Dynamite, 1877	..	..	18·18 18·16	..	..
Nitrated Hydro-Cellulose. Zamky, 1879	..	12·05 12·31	..	12·26	..
English paper powder from Prentice and Co., Stowmarket	..	..	9·82	..	9·82

calcium chloride or sulphuric acid for at least two days. Let us assume that before drying we had the following weight—

Watch glass with powder . . .	5·7412	grams
,, ,, without powder . .	3·8534	,,
Dynamite	1·8878	,,

and after drying we had—

Watch glass with powder . . .	5·7176	,,
,, ,, without powder . .	3·8534	,,
Dynamite	1·8642	,,
Deducting from . .	1·8878	
	1·8642	
There remains	0·0236	grams.

or 1·25 per cent. for moisture.

Then having prepared two filtering-papers of exactly equal size and weight, we take a thin beaker, 1¾ in. wide by 1½ in. high, and weigh it accurately, and put it under a glass funnel which is provided with a loose stopper of cotton placed in the neck, and introduce the weighed filter paper into the funnel. The loose stopper of cotton under the filter paper prevents the too fast passing through of the ether. The filter paper is slightly moistened with ether, the dynamite put into it, and is treated with repeated washings of ether, until this has been done six or eight times, when all the nitro-glycerine will have been dissolved and filtered into the beaker.

A very simple way of ascertaining if any nitro-glycerine is yet passing in the solution, is by dropping two or three drops on a piece of writing paper, when if there is only a trace of nitro-glycerine the paper will show a greasy spot. As soon as the filter paper is dry, it is cleaned with ether and then ignited together with its contents in a platinum dish of known weight. When a uniform colour has been obtained it is allowed to cool, and then weighed.

As a result we have :—

Weight of platinum dish and contents . . .	15·6616 grams.
,, ,, alone	15·1769 ,,
Therefore Kieselguhr and ash	0·4847 ,,

Then the second filter paper, of exactly the same weight as the one used, is reduced to ashes in the platinum dish and again weighed.

Weight of platinum dish and contents . . .	15·1780 grams.
,, ,, ,, alone	15·1769 ,,
,, ash	0·0011 ,,
The Kieselguhr equals 0·4847 – 0·0011 . .	0·4836 ,,

equal to $23\frac{46}{100}$ per cent.

The nitro-glycerine can be determined now by the loss, but the percentage of it is ascertained as follows: a water bath, covered with a sheet of tin and a wire netting, is heated to about 70° centigrade, the beaker with its filtrate is put on the wire netting. The ether must not boil, but slowly evaporate; and as soon as it has nearly all evaporated, the flame is repeatedly withdrawn. The filtrate will soon assume a milky appearance, and when this takes place the beaker is lifted several times and shaken a little to stir up the contents. When all the ether has evaporated the remainder consists of nitro-glycerine and acetic ether, which can be evaporated by continued heating over the water bath. If an air-pump is at hand, even the smallest traces of acetic ether can be extracted. We have now :—

Weight of beaker with contents	42·9550 grams.
,, ,, alone	41·5744 ,,
Nitro-glycerine . . .	1·3806 ,,

or $75\frac{26}{100}$ per cent. The explosive examined is therefore composed of—

Nitro-glycerine	75·26 per cent.
Kieselguhr	23·46 ,,
Moisture	1·25 ,,

A detailed examination of the Kieselguhr must be made under a microscope (900) magnifying power, to ascertain whether it contains a heavy percentage of Bacillariæ and Pleurosigmata (the first-named infusoria to be largely in excess), but no grains of quartz and no wheel-shaped Dictyodaceæ. A good Kieselguhr is absolutely necessary for good guhr dynamite, bad Kieselguhr, even with the same percentage of nitroglycerine makes a weaker dynamite.

Explosive Gelatine.—The analysis of this substance is made as follows: About 1·5 to 2 grams of gelatine is taken and weighed; assuming that we have—

Beaker with explosive	42·2103 grams
,, alone	41·5305 ,,
Then gelatine	1·6798 ,,

A few drops of alcohol are then poured upon the gelatine, and after that, an excess of ether, until the nitro-glycerine and nitro-cellulose is completely dissolved. Then an excess of chloroform is added. Two filtering-papers exactly alike are cut, and one of them laid in a glass funnel. The solution of chloroform containing the nitro-glycerine and the nitro-cellulose is then filtered into a beaker of known weight and frequently wet with chloroform. The filtrate is then chloroform and dissolved nitro-glycerine, while the remainder is nitro-cellulose.

The filtering-paper is then taken from the funnel, the chloroform remaining about the filter allowed to evaporate, and the funnel thoroughly cleaned with chloroform. Then the filter-paper with the nitro-cellulose and the other filter not used are put over a water bath for about fifteen minutes at a temperature of 100° Centigrade, and both filters then weighed. The difference in their weight gives the proportion of nitro-cellulose; say in this case the difference is 0·1243 gram or 7·4 per cent. nitro-cellulose.

The filtered fluid is then treated as in the first test, with the result:—

Weight of beaker with contents .	43·0683 grams.
,, ,, alone	41·5308 ,,
Hence nitro-glycerine . .	1·5555 ,,

or 92·6 per cent. The explosive gelatine consequently contains

Nitro-glycerine	92·6 per cent.
Nitro-cellulose	7·4 ,,

It is advisable to determine the moisture in the gelatine before its solution in ether and alcohol.

New Dynamite No. 1.—Weigh out about 2·5 to 3 grams, and dry for about three days in an exsiccator; it is then weighed again.

Say the following are the results:—

Watch glass with contents . .	8·2939 grams
,, ,, alone.	5·3538 ,,
Hence dynamite with moisture	2·9401 ,,

and after drying in the exsiccator, we have—

Watch glass with contents . . .	8·7616 grams
,, ,, alone	5·8538 ,,
Hence dynamite	2·9078 ,,

2·9401 − 2·9078 = 0·0323 gr. = 1·10 per cent. moisture.

The dynamite in the beaker is then moistened with some alcohol, then ether is added until the nitro-glycerine and the gun-cotton are completely dissolved. It is then filtered through a filtering-paper of known weight, and washed with ether. The ether and alcohol is then evaporated and the filtering-paper is dried at about 100° C. The filtered fluid is then covered with chloroform which separates the nitro-glycerine from the gun-cotton. The process is now the same as that with explosive gelatine, described above. When the dry filter-paper is weighed we have—

Weight of filter paper with contents . . .	1·3858 grams
,, ,, ,, alone	0·7623 ,,
Therefore absorbents alone	1·0735 ,,

or 36·51 per cent.

The paper with the absorbent is then put into the funnel, and is repeatedly wet with boiling water until the saltpetre and soda is dissolved. The filtered fluid is now put in a platinum dish and carefully dried over a water bath, and after having been left for twenty-four hours over the exsiccator, it is weighed.

Platinum dish with contents . . .	15·9322 grams
,, ,, alone	15·1769 ,,
Hence saltpetre and soda . . .	0·7553 ,,

Besides these two substances the residue contains the soluble parts of the wood pulp. For ordinary purposes this analysis is sufficient, and we have for the explosive examined :—

Moisture	0·0323 gram	or	1·10	per cent.
Saltpetre, soda and dissolved pulp	0·7553 ,,	,,	25·68	,, ,,
Wood pulp	0·3182 ,,	,,	10·82	,, ,,
Gun-cotton	0·0647 ,,	,,	2·20	,, ,,
Nitro-glycerine	1·7693 ,,	,,	60·17	,, ,,
Loss	0·0003 ,,	,,	0·03	,, ,,
	2·9401		100·00	

If an exact analysis is desired, then, after the above-described proceeding we must determine the residue in the filtering paper :—

Paper with residue	1·0805 gram	
,, alone	0·7623 ,,	
Therefore dried wood pulp . . .	0·3182 ,,	or 10·82 per cent.

Then a few drops of water with one drop of nitric acid are added to the salts in the platinum dish, and after that it is dried and weighed. From the difference the percentage of soda can be calculated, as the sodium carbonate has been changed by the nitric acid into sodium nitrate. For instance, let the first weight of saltpetre, soda, and dissolved wood pulp (as above) 0·7553 gram = P; the second weight = 0·7450 gram = P, therefore difference = 0·0103 gram. The molecular weight of sodium nitrate is 85, twice the same = 170;

the molecular weight of sodium carbonate = 106. We have then the proportion :—

$$106 : (170-106) = x : 0{\cdot}0103$$

or $$106 : 64 = x : 0{\cdot}0103$$

hence $$x = \frac{106 \times 0{\cdot}0103}{64} = 0{\cdot}0171 \text{ gram of sodium carbonate.}$$

To ascertain the percentage of the dissolved wood pulp, the contents of the platinum dish are heated until the saltpetre is melted; it is then cooled, a little water and a drop of nitric acid added, and then dried over steam. The dish is then heated to 150° C., dried in an exsiccator and weighed :—If, for instance, the weight of the dish and contents is 0·7273 gram, then $P' = 0{\cdot}7450$, $P'' = 0{\cdot}7273$; the difference is 0·0177 gram; equal to the weight of the dissolved constituents of the wood pulp. The above given weight of 0·7553 gram has the following composition :—

Potassium nitrate.	0·7205 gram	= 24·50 per cent.
Sodium carbonate	0·0171 ,,	= 0·58 ,, ,,
Dissolved wood pulp	0·0177 ,,	= 0·60 ,, ,,
	0·7553 ,,	= 25·68 ,, ,,

These examples show that an analysis of dynamite can be made at a small expense of time and means; all that is needed is careful, intelligent work, and a good balance which is accurate to $\frac{1}{10000}$ of a gram.

II.—Composition of Gun-cotton Samples.

The gun-cotton prepared after the Lenk-Abel system shows a variable composition, as will appear from the table of results of analyses given below, which has been compiled by several observers, although the analyses were conducted on one and the same method, as follows :—

a. **Determination of Moisture.**—As in compressed gun-cotton the moisture is not evenly distributed throughout the whole mass, it becomes important to obtain an average sample. This is best obtained by dividing several cartridges into thin discs and sampling these perfectly. The divided gun-cotton is now weighed in a glass tube, which can be hermetically closed, and the weight of which has been previously taken; it is exposed in this to the influence of a current of dry air at a temperature of 40° C., until its weight remains constant. To prevent any of the powdered gun-cotton from being carried away by the current of air, the outlet of the tube is closed by a cotton stopper. Parts of this sample are then taken for analysis, the weight of the tube being taken each time, so as to determine by the difference of weight how much of the gun-cotton has been taken out.

b. **Determination of Ash.**—A certain weight of the gun-cotton is saturated with paraffin (about 5 grams will suffice) in a platinum-dish and set on fire, and the residue weighed.

c. **Extraction of Alkalies.**—A certain quantity of dried gun-cotton is leached out with water, which dissolves any alkaline carbonates present. An addition of a carbonate of an alkaline earth is found by the analysis of the ash. All of the ash that is not soluble in hydrochloric acid, can be considered as sand.

d. **Determination of the contents of Mono– and Dinitro–Cellulose.**—About 5 grams of the triturated and dried gun-cotton are saturated in a flask with absolute alcohol, and then ether is added. The flask is closed with a cork and left standing at the ordinary temperature of the room, shaking it gently occasionally till all the fibres are dissolved. Alcohol ether is now added till the solution is perfectly fluid, and it is now passed through a linen filter. Should the filtrate appear turbid, it is repeatedly passed through the filter. After carefully washing the filter with alcohol-ether it is dried in a current of air of 40° C. and again weighed. The difference between the weight of the gun-cotton sample itself and the weight of the residue on the linen filter gives the contents of mono- and dinitro-cellulose.

The residue consists of ash particles insoluble in water, of trinitro-cellulose and unnitrated cotton fibres.

e. **Separation of Trinitro-cellulose from the Unnitrated Cotton-fibres.**—A portion of the residue from *d* is weighed out in a test tube, and repeatedly boiled with an excess of concentrated sodium sulphate. The trinitro-cellulose goes into solution; whereas the unnitrated fibres are not attacked.

The solution is passed through a weighed linen filter and washed with distilled water, till the drops of filtrate do not impart a brown colour to paper saturated with lead acetate. The filter is now washed with dilute hydrochloric acid, to wash out traces of sulphate of iron, and at last is washed with distilled water to free it from hydrochloric acid, then dried at 40° C. in a current of dry air and weighed.

It is advisable to examine the residue obtained once more by repeating the whole process, so as to see if any trinitro-cellulose remains. The residue must not be considered as pure cotton, but must be incinerated, and the ashes leached out with hydrochloric acid and the residue which is insoluble must be weighed out. As an explanation of the subjoined Table, it must be first noticed that—

Samples *a* and *b* are from the gun-cotton factory at Kruppamühle in Upper Silesia.

Samples *c* and *d* are gun-cotton from some other continental factory.

Sample *e* is English gun-cotton extracted from a blasting compound named "Tonite," from the cotton-powder factory at Faversham.

Samples under *g* and *h* indicate the composition of Abel's gun-cotton according to Musprat.

Sample *i* gives the composition of a sample of English gun-cotton (which has been freed of its ash, amounting to 1 per cent.) according to Champion and Pellet. But instead of indicating the highest nitrated product of cotton by the name of trinitro-cellulose, Champion and Pellet by doubling the cellulose formulæ used the name "Pentanitro-Cellulose."

TABLE SHOWING THE COMPOSITION OF SOME GUN-COTTON SAMPLES PREPARED AFTER LENK'S AND ABEL'S METHODS.

Denomination of the sample.	Percentage of the sample in						Totals.	By whom the Analysis made.	REMARK.
	Trinitro-Cellulose.	Mono- and Dinitro-Cellulose.	Cellulose.	Extracted with water.	Sand.	Other Ash residues.			
A	88·60	5·51	3·30	1·64	0·37	0·17	99·59	Captain Hess.	
B	89·10	5·57	3·28	1·40	0·33	0·69	100·37	Second Lieutenant Dolliak.	
C	80·33	9·44	8·40	0·25	0·06	1·56	100·04	Captain Hess.	
D	80·57	9·20	8·41	0·26	0·05	1·60	100·09		
E	85·53	6·45	3·57	2·43	0·22	1·86	100·06	Second Lieutenant Dolliak.	
F	93·13	5·63	1·05	..	0·19		100·00	Captain Hess and Captain Schwab.	This sample taken from Tonite.
G	81·5	12·0	5·0	0·5			99·50		
H	82·5	12·0	4·0	0·5			99·50		
I	93·0	6·0	1·0	..	..	..	100·00	Champion and Pellet.	

Determination of the Ash Residue of Gun-cotton.—In incinerating gun-cotton, collodion-cotton, or any other nitro-cellulose, in consequence of the rapid development of gas the ashes are blown away from the vessel, and an exact determination of the ashes becomes difficult.

To avoid this the weighed quantity of gun-cotton is impregnated with paraffin. The burning proceeds now slowly, and there is no loss of ashes. The *modus operandi* is as follows:

A quantity of clear paraffin, just sufficient to impregnate the gun-cotton, is melted in a platinum dish. An excess of paraffin is not objectionable. After the gun-cotton is soaked it is set on fire. The contents of the dish do not burn now any faster than pure paraffin would. There remains a carbonaceous residue, which can be incinerated.

The results obtained in this manner by Captain Hess are very satisfactory, and a sample of gun-cotton from a German factory gave, after two trials, a percentage of ash of 2·40 and 2·41 per cent. A second assay gave 2·44 and 2·56 per cent., and a third assay gave 2·33 and 2·34 per cent.

A sample of English gun-cotton gave in three determinations an ash content of 4·24, 4·19 and 4·11 per cent.

III.—QUALITATIVE AND QUANTITATIVE CHEMICAL ANALYSIS OF NITRO-GLYCERINE COMPOUNDS.

Ingredients of Nitro-glycerine Compounds.—In the determination and separation of the ingredients which are contained in the various nitro-glycerine compounds, account is taken of the various parts which they play, and hence they are classified as follows:—

1. Explosive ingredients.
2. Absorbents which are non-explosive and play no part in the explosion.
3. Absorbents which are chemically active and which are subdivided into:—
    - *a.* Mineral absorbents.
    - *b.* Organic absorbents.

4. Oxidising agents, which promote the combustion of the organic absorbents during the explosion.

5. Ingredients which contribute to the stability of the explosive compounds.

6. Ingredients which are intended to impart certain advantageous technical properties to the nitro-glycerine compounds, besides the explosive effect.

1. As explosive ingredients of the nitro-glycerine compounds we have: Nitro-glycerine, gun-cotton, collodion-cotton, nitrated wood fibres.

2. As absorbents, which are non-explosive, and play no part during the explosion, we have: Kieselguhr, Randanite, Tripoli clay, and argillaceous earth.

3*a*. Mineral absorbents, which act chemically through the volatile gases which are developed by the heat generated during the explosion, such as chalk, carbonate of magnesia.

3*b*. Organic absorbents, such as sawdust, wood pulp, paper pulp, charcoal, brown coal and stone coal.

4. As mineral oxygen carriers we have: Saltpetre, nitrate of soda, nitrate of ammonia and nitrate of baryta. Sometimes chlorate of potash is used, as in Séranine and Horsley powder.

5. The ingredients which contribute to the stability of the explosive compounds are generally the carbonates of the alkalies and alkaline earths, like carbonate of soda, carbonate of ammonium, carbonate of lime, carbonate of magnesia. The two last serve also as absorbents for the nitro-glycerine.

6. Other additions are: Paraffin, sulphur, resin and other substances which are utilised to modify the absorbing capacities of the absorbents and diminish their hygroscopic properties. To diminish the sensitiveness of the nitro-glycerine to mechanical and thermal influences, camphor is added in some instances.

Qualitative Examination of Nitro-glycerine Compounds.—For the qualitative examination of the nitro-glycerine compounds, the following advice is given:

The compound is very finely divided, which is done by cutting the gelatine into very thin sections, and when the compound is pulverulent it is treated with ether, but when gelatinous, with a mixture of two parts of ether and one of alcohol. In the first case, the nitro-glycerine is extracted, and if paraffin, sulphur, resin or camphor is present, they are also dissolved. In the second case the collodion-cotton is also dissolved.

Reactions of the Nitro-glycerine.—The ether solution is evaporated on a water bath at a temperature of about 30° C. To prove the presence of the nitro-glycerine as such, a drop of it is taken out on a piece of blotting-paper and is hammered on an anvil, which causes an explosion.

The portion dissolved in alcohol and mixed with an alcoholic solution of ammonium sulphide will cause the separation of sulphur.

A solution of ferrous sulphate, to which a few drops of muriatic acid are added, will give, when a drop of nitro-glycerine is added and on slightly warming, the nitrogen-oxide reaction.

On adding a drop of the oil to an iodide of potassium and starch solution, acidulated with dilute sulphuric acid and containing some zinc filings, a blue coloration of the liquid will be produced.

If after evaporation of the ether the oil shows a specific gravity of 1·6 and has no smell, it can be concluded that it is pure nitro-glycerine.

In making these tests pure ether must be employed, as otherwise the impurities which are less volatile will be found in the residue. This will be especially the case with acetic ether.

Reactions for Paraffin, Sulphur, and Resin.—If after the evaporation of the ether (when the solution is completed) the residue is carefully examined, and if the presence of paraffin, sulphur, and resin is suspected, then the nitro-glycerine is decanted, and the residue pressed between filtering-paper as long as it shows any fat.

By boiling the residue with soda solution the resin is first dissolved.

Another portion of the residue after drying is treated with aqua regia, by which any sulphur will be converted into sulphuric acid, which is then precipitated as barium sulphate.

Another portion of the residue is boiled with a solution of ammonium sulphide, whereby the sulphur dissolves and forms ammonium polysulphide, and the paraffin after cooling collects as a crust on the surface of the liquid, and can be washed with water, dried and subjected to a further examination.

The test for paraffin can also be made after the evaporation of the ether from the oil, by taking some of the sample and treating it with alcohol, and pressing between filter-paper till all the liquid is absorbed. Then the residue is tested as to its fusibility and its boiling-point, and the smell of its distillation products noticed.

The resin which may be present can be saponified by boiling with soda solution, from which the resin can be precipitated by hydrochloric acid.

Reactions of Collodion-cotton and Camphor. — If the ether solution contains camphor, this is recognised at once by its smell.

If the explosive is treated with a mixture of alcohol and ether, then on addition of chloroform the mono- and dinitrocellulose is separated. By now heating gradually from 30° to 80° C., the solution is freed from ether, alcohol, and chloroform.

The mono- and dinitro-cellulose which is separated is recognised by its explosibility when struck with a hammer on an anvil; and also through its deportment with sodium sulphide solution, in which it dissolves on boiling. By boiling it with hydrochloric acid and ferrous sulphate it ought to give the nitrogen oxide reaction.

Reaction of the Nitrates, Chlorates, and Carbonates soluble in Water.—The residue from the extraction of the explosive with ether or alcoholic ether is now treated with hot distilled water, whereby the nitrates, chlorates, and those carbonates which are soluble in water go into solution. The determination of these substances in the aqueous solution offers no difficulty. The residue which remains after leaching with hot water, if the explosive in the first instance has only been treated with ether, may contain mono-, di- and trinitro-cellulose, but if the extraction has been carried on with alcoholic-ether only trinitro-cellulose, the higher nitro-products, and all the other substances which are insoluble in alcohol, ether and water.

Reaction for Trinitro-cellulose. — The presence of trinitro-cellulose in the residue is determined :—

1. By examining the residue under the microscope by means of polarised light; the trinitro-cellulose shows the original structure of the cotton fibres, but they are of a dull aspect, while the unnitrated fibres show a very vivid play of prismatic colours.

2. By boiling the residue with ferrous sulphate solution and hydrochloric acid, the nitrogen oxide reaction will set in if any trinitro-cellulose is present.

3. On boiling the residue with an alcohol solution of caustic potash, when the filtrate is slightly acidulated with sulphuric acid, free nitric or nitrous acid ought to be recognised.

4. On separating the fibres taken for trinitro-cellulose, and examining them in regard to their inflammability and explosibility. The trinitro-cellulose can be separated from the residue, by boiling it with sulphide of sodium solution, filtering and washing with distilled water, which will leave the other insoluble ingredients behind.

Reaction for Carbonate of Lime, Carbonate of Magnesia, and Argillaceous Earth.—When the residue which contains these substances is treated with hydrochloric acid, the carbonate of lime, carbonate of magnesia, and also the argillaceous earth, goes into solution, and the substances enumerated under 2 and 3*b* remain behind.

Examination of the Residue: Wood, Coal, Insoluble Mineral Substances.—The residue is examined under the microscope. Sawdust, wood pulp, and charcoal are easily recognised by their structure and colour.

The wood fibres can be dissolved with caustic potash solution, and are precipitated with a brown colour by means of acids.

Brown coal will also enter into solution with caustic potash.

The residue when incinerated will yield beside wood and stone coal ash, any mineral substances which may have been contained in the explosive substance. The microscope must have detected the kieselguhr beforehand, if any was present.

Quantitative Examination of Nitro-glycerine Compounds.—A. *Extraction with Ether.*—The extraction of the nitro-glycerine, in most cases, is best effected with ether. Ether is the best solvent for nitro-glycerine on account of its great volatility, and also because ether leaves nearly all other substances behind without acting on them as a solvent.

The sample which is submitted for analysis is first dried under the exsiccator over *chloride of calcium.* The use of sulphuric acid for drying nitro-glycerine and similar compounds, as well as fulminates, ought to be avoided in all cases, *as serious accidents might happen by spilling some of the explosive into the acid.* The sample is now treated on a filter with ether, as fully described previously.

The ether solution is collected in a small beaker, previously weighed, and evaporated on a water bath. There is a moment during the evaporation when the clear liquid, in consequence of the partial separation of the nitro-glycerine from the ether, shows a milky turbidity; and the operation is now closely watched till this turbidity disappears, when the beaker is at once taken away from the bath. The nitro-glycerine still contains small quantities of ether, or acetic ether, and to free it from these traces and also from moisture, it is put again under the vacuum of an air-pump over chloride of calcium. The nitro-glycerine can be weighed as soon as no smell of ether is noticed, and the operation is repeated until the weight is constant.

Determination of the Nitro-glycerine in the presence of Paraffin, Resin, or Sulphur. Determination of these Substances.—If the explosive contains beside nitro-glycerine other substances, like paraffin, resin, or sulphur, which are also soluble in ether, these go into solution along with it. After evaporation of the ether, the nitro-glycerine, with the adhering substances, is weighed and then heated on a water bath with a soda solution. The resin goes into solution, and is separated by decantation from the rest, precipitated with hydrochloric acid, and collected on a weighed filter, previously dried at a temperature of 100° C., washed, and again dried as before, and weighed. The nitro-glycerine is taken up with strong alcohol, decanted, and the remaining mixture of paraffin and sulphur washed with alcohol, then dried and weighed.

To separate the sulphur from the paraffin, the mixture is heated with a solution of ammonium sulphide in water. After cooling the paraffin collects as a crust on the surface, and by pricking a small hole through it the liquid underneath is poured off, and after washing with water and drying the paraffin is weighed.

The quantity of the nitro-glycerine and that of the sulphur is determined by difference.

B. *Extraction with Ether-Alcohol. Determination of the Nitro-glycerine in Gelatinised Explosives. Determination of the other Substances which can be Extracted with Alcoholic Ether.*—In acting on gelatinised materials, it is better to use alcoholic ether and to dissolve the nitro-glycerine and collodion-cotton at once, and to precipitate the collodion-cotton by adding chloroform.

If camphor is present it is extracted with bisulphide of carbon after the compound is treated with the ether-alcohol.

In case any paraffin, sulphur, or resin is present they will go over into solution with the camphor in the sulphide of carbon, and the easily volatile camphor can be separated by evaporation from the difficultly volatile paraffin, resin, or sulphur. If the weight of the extract freed from ether-alcohol but not yet treated with bisulphate of carbon is $= a$; and if the weight of the extract after treatment with bisulphide of carbon and evaporation of the same is $= b$; and if the weight of the residue which is left after evaporating the bisulphide of carbon and the camphor it held in solution is $= c$; we find the percentage of camphor to be: $a - b - c$.

The residue c may contain traces of nitro-glycerine, some paraffin, resin, or sulphur, and their separation may be effected by the method described beforehand.

C. *Separation and Determination of the Ingredients which are Insoluble in Ether and Ether-Alcohol.*—In the residue which remains after the treatment of the explosive with ether and alcoholic ether, there may be present some bodies enumerated under 2, 3*a*, 3*b*, 4 and 5.

If, according to the qualitative analysis the residue, consists of refractory substances, they can be incinerated with the filter and weighed. But it is better first to dry the filter in a current of dry air at 60° C., and to weigh, and then burn the filter and weigh again, and determine by this means whether or not the residue contained small quantities of organic substances.

If the residue contains other ingredients, it is treated in the following manner:—

Extraction with Water.—If soluble salts are present, after the weight of the residue on the filter is determined, they are leached out with hot distilled water, the filtrate evaporated, dried at 120° C., and its weight determined. If the extract contains carbonates and no chlorates, the residue is dissolved again in water, neutralised with nitric acid, evaporated on a water bath, dried at 120° C., and again weighed. By this proceeding the carbonates are converted into nitrates, and from the difference of the two weighings the quantity of carbonic acid is determined.

The separation of the different bases is carried out according to the known analytical methods.

In case any chlorates are present in the aqueous solution of the soluble salts, a portion of it is taken, and the carbonic acid is first determined as calcium carbonate through precipitation with calcium nitrate, and after separation of the precipitate the solution is evaporated and heated and the chloric acid determined as silver chloride.

Another portion of the aqueous solution is taken for the purpose of determining the nitric acid through conversion into ammonia.

The determination of the different bases is carried on with still a separate portion of the aqueous solution. The residue which is left after the extraction with water is treated as follows :—

Separation and Determination of Trinitro-cellulose.—If trinitro-cellulose is present, then a part is taken from the filter and boiled in a concentrated solution of sodium sulphide. The nitro-cellulose goes thereby into solution, and is passed through a weighed filter, which is carefully washed with distilled water, dried and weighed. The difference of weight gives the percentage of trinitro-cellulose.

Extraction with Hydrochloric Acid. —The residue which remained on the above filter, after separating from it the trinitro-cellulose, is treated with dilute hydrochloric acid, which dissolves out the carbonates of lime and magnesia and also the argillaceous earth, and in the solution the different bases are determined. The residue is washed with water, and after drying is weighed on a filter, and from the difference or weight the quantity or alkaline and earthy carbonates is found.

Determination of the Organic and Inorganic Absorbents.—This residue contains, besides the wood, coal or similar organic substances, the insoluble mineral absorbents also.

Through incineration the organic substances can be separated, and the insoluble mineral substances are weighed as a residue. If there are several organic absorbents, such as wood pulp and charcoal, a satisfactory separation of these two substances cannot be made here, but they must be determined by means of an elementary organic analysis, which will establish the relative proportion of these ingredients quite approximately.

Notes as to the Analysis of Nitro-gelatine containing Camphor.—To determine the camphor, the nitro-gelatine is cut into very thin slices and digested in a flask with a mixture of alcohol and ether at a temperature of 30° C. About 30 cubic centimetres of the solvent are taken for 0·3 grams of the gelatine, and the solution is effected after several hours, with the exception of some pentanitro-cellulose and unnitrated cotton.

The clear solution is poured into a beaker and the flask washed with a little ether, and this added to the solution in the beaker. The whole is now mixed with about three times its volume of chloroform, which separates the collodion-cotton as a gelatinous mass, and this is collected on a linen filter, air-dried at 70° C. and weighed. The filter is washed with a little chloroform. After drying the filter, its increase in weight determines the quantity of collodion-cotton.

The filtrate is kept at a temperature of 30° C., and after being put over chloride of lime in the vacuum of an air-pump, it is freed from the alcohol-ether, chloroform and moisture, and the nitro-glycerine and camphor remains.

A portion of this remaining solution of camphor in nitro-glycerine is now taken in a test tube and mixed with 20 c.c. of bisulphide of carbon and well shaken. The camphor and a very small portion of nitro-glycerine dissolve in the bisulphide of carbon, and this solution is now decanted from the remaining nitro-glycerine. The nitro-glycerine and the decanted liquid are exposed first to a temperature of 20° C., then to 60° C., and at last in the vacuum of an air-pump over calcium chloride till the bisulphide of carbon in both samples, with the camphor contained in one, is evaporated. The evaporation of the camphor is noticeable by the smell. The test tube which contained the bisulphide of carbon shows now a few drops of nitro-glycerine, which were dissolved with the camphor and which has separated now from it. The principle of this method therefore consists in dissolving the camphor, which is held with great tenacity by the nitro-glycerine, in bisulphide of carbon.

A very small quantity of nitro-glycerine is lost by this method through its volatilisation with the bisulphide of carbon, and it is of importance to determine this loss, so as to correct the weight of the separated nitro-glycerine. Captain Hess made several tests, to determine the loss occasioned in this way, by shaking well together 4 to 5 grams of nitro-glycerine and 20 c.c. of bisulphide of carbon, decanting and evaporating as before stated. The nitro-glycerine weighed afterwards showed by repeated tests an average loss of 1·25 per cent.

Hence in an analysis of nitro-gelatine, containing camphor, this quantity has to be added to the weight of nitro-glycerine found. The quantity of camphor is therefore determined by difference. A small quantity of camphor is also lost during the evaporation of the ether-alcohol and chloroform solution, and this loss has to be determined. To see how exact this method is, Captain Hess prepared several samples of nitro-gelatine himself, and from the synthetic conditions and the results of the analysis he found it satisfactory. From 100 parts of dry camphor gelatine he obtained

	According to Synthesis.	According to Analysis.
Nitro-glycerine	85·25	85·33
Collodion-cotton	8·74	9·00
Camphor	6·01	5·67
	100·00	100·00

APPENDIX B.

DETERMINATION OF STABILITY.—INSTRUCTIONS AS TO TESTS ISSUED BY THE HOME OFFICE.*

Heat Test as applied to Explosives of the Nitro-compound Class (as defined by Order in Council, No. 1, of 5th August, 1875).

General Instructions.

Apparatus required.

1. A water bath, consisting of a spherical glass or copper vessel (*a*), Fig. 102, of about 8 inches diameter, and with an aperture of about 5 inches; the bath is filled with water to within a quarter of an inch of the edge. It has a loose cover of sheet copper about 6 inches in diameter (*b*), and rests on a tripod stand about 14 inches high (*c*), which is covered with coarse iron wire gauze (*e*), and is surrounded with a screen of thin sheet tin or copper (*d*). Within the latter is placed an argand burner (*f*) with glass chimney. The cover (*b*) has four holes arranged as seen in Fig. 103, No. 4 to receive the regulator, No. 3 the thermometer, Nos. 1 and 2 the test tubes containing the gun-cotton or other materials to be tested. Around holes 1 and 2 on the under side of the cover are

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* I am indebted to Colonel V. D. Majendie, H.M. Chief Inspector of Explosives, for a copy of these Instructions.

soldered three pieces of brass wire with points slightly converging (Fig. 103); these act as springs and allow the test-tubes to be easily placed in position and removed.

*2. Scheibler's or Page's temperature regulator.

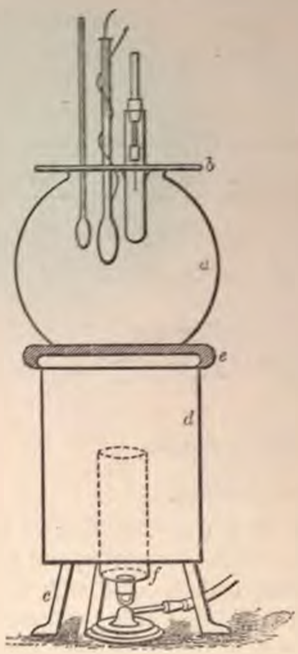

FIG. 102.

FIG. 103.

SIR FREDERICK ABEL'S HEAT TEST APPARATUS.

*3. Two cells of Le Clanché's battery No. 1 } if Scheibler's regulator is used.
*4. A few yards of insulated copper wire }

5. Test tubes from $5\frac{1}{4}$ to $5\frac{1}{2}$ inches long, and of such diameter that they will hold from 20 to 22 cubic centimetres of water when filled to a height of 5 inches.

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* This is not absolutely required, as the temperature of the bath can be kept constant by proper attention to the heating flame.

6. India-rubber stoppers, fitting the test tubes and carrying an arrangement for holding the test paper, viz., a narrow glass tube passing through the centre of the stopper, drawn out so as to form a hook, or terminating in a platinum wire hook (Fig. 103).

7. A thermometer, with range not less than from 30° to 212° Fahrenheit.

8. A minute clock.

Materials Required.

a. *Test Paper.*—The test paper is prepared as follows:—45 grains of white maize starch (corn-flour), previously washed with cold water, are added to 8½ oz. of distilled water; the mixture is stirred, heated to boiling, and kept gently boiling for ten minutes; 15 grains of pure potassium iodide (*i.e.* which has been re-crystalised from alcohol) are dissolved in 8½ oz. of distilled water. The two solutions are thoroughly mixed and allowed to get cold. Strips, or sheets, of white English filter paper, previously washed with water and re-dried, are dipped into the solution thus prepared, and allowed to remain in it for not less than ten seconds; they are then allowed to drain and dry in a place free from laboratory fumes and dust. The upper and lower margins of the strips, or sheets, are cut off and the paper is preserved in well-stoppered or corked bottles **and in the dark.** When the paper is freshly prepared, and as long as it remains in good condition, a drop of dilute acetic acid, put on the paper with a glass rod, produces no coloration. In process of time, however, the stronger the light to which the paper is exposed, the sooner a drop of the acid produces a brown or bluish coloration (a single hour of direct sunlight produces a marked effect), and whenever this is the case the paper should be rejected. On this account it is advisable not to prepare too much of the test paper at one time, but to prepare it fresh every month or so.

b. *Standard Tint Paper.*—A solution of caramel in water is made of such concentration that when diluted one hundred times (10 c.c. made up to 1 litre) the tint of this diluted solution equals the tint produced by the Nessler test in 100 c.c. water containing 0·000075 grm. of ammonia or 0·00023505 grm. of chloride of ammonium. With this caramel solution lines are drawn on strips of white filter paper (which paper must be carefully washed with distilled water in the first instance, to remove any traces of bleaching matter, and dried) by means of a clean quill pen. When the marks thus produced are dry the paper is cut into pieces of the same size as the test paper previously described, in such a way that each piece has a brown line across it near the middle of its length, and only such strips are preserved in which the brown line has a breadth varying from $\frac{1}{2}$ mm. to 1 mm. ($\frac{1}{50}$ inch to $\frac{1}{25}$ inch).

Testing Dynamite, Blasting-Gelatine, and other Explosives of the First Division of the Nitro-compound Class.

A.—Dynamite, &c., &c.

Nitro-glycerine preparations, from which the nitro-glycerine can be extracted in the manner described below, *must* satisfy the following test, otherwise they will not be considered as manufactured with "thoroughly purified nitro-glycerine" within the terms of the license.

This test, however, though at present looked upon as the most important, as far as testing the purity of the nitro-glycerine is concerned, is only one of several which any given sample of nitro-glycerine preparation has to satisfy in order to establish its compliance with the definition in the license.

The test, although at present accepted as regulating and defining the meaning of the terms "thoroughly purified," may nevertheless be modified or superseded if, in the opinion of the Home Office, such alteration may at any time be deemed necessary.

Apparatus Required.—A funnel 2 inches across (*d*) a cylindrical measure divided into grains (*e*), see Fig. 105.

Mode of Operation.—About 300 to 400 grains of dynamite (*b*) finely divided are placed into the funnel, which has previously been loosely plugged by some freshly ignited asbestos (*a*).

The surface is smoothed by means of a flat-headed glass rod or stopper, and some clean washed and dried Kieselguhr (*c*) is spread over it to the depth of about ⅛ inch.

FIG. 104.

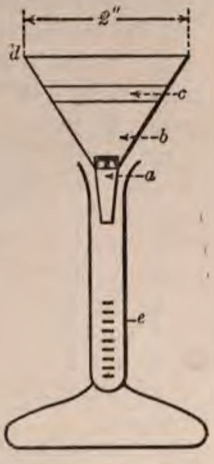

FIG. 105.

SIR FREDERICK ABEL'S HEAT TEST APPARATUS.

Water is next carefully dropped from a wash bottle upon this Kieselguhr, and when the first portion has been soaked up, more is added; this is repeated until sufficient nitroglycerine has been collected in the graduated measure (*e*) below.

If any water should have passed through with the nitroglycerine, it should be removed with a piece of blotting-paper, and the nitro-glycerine, if necessary, filtered through a dry paper filter.

Application of the Test.—The thermometer is fixed so as to be inserted through the lid of the water bath described before into the water (which is to be steadily maintained at a temperature of 160° Fahr.) to a depth of 2¾ inches. Fifty grains of nitro-glycerine, to be tested, are weighed out into a test tube in such a way as not to soil the sides of the tube. A test paper is fixed on the hook of the glass rod so that when inserted into the tube it will be in a vertical position. A sufficient amount of a mixture of half distilled water and half glycerine to moisten the upper half of the paper is now applied to the upper edge of the test paper, by means of a camel's-hair pencil, the cork carrying the rod and paper is fixed into the test tube and the position of the paper adjusted so that its lower edge is about half-way down the tube; the latter is then inserted through one of the perforations of the cover, to such a depth, that the lower margin of the moistened part of the paper is about ⅝ of an inch above the surface of the cover. The test is complete when the faint brown line, which after a time makes its appearance at the line of boundary between the dry and moist part of the paper, equals in tint the brown line of the standard tint paper.

The nitro-glycerine under examination will not be considered as *thoroughly purified* within the terms of the license, unless the time necessary to produce the standard tint as above described IS AT LEAST 15 MINUTES.

B.—Blasting-Gelatine, Gelatine Dynamite, and Analogous Preparations.

Fifty grains of blasting-gelatine are to be intimately orporated with 100 grains of French chalk. This may readily effected by carefully working the two materials r with a wooden pestle in a wooden mortar. The s to be gradually introduced into a test tube of the recommended above for the dynamite heat test, with the aid of gentle tapping upon the table, between the introduction of successive portions of the mixture into the tube, so that when the tube contains all the mixture it shall be filled to the extent of 1¼ inch of its height. The test paper is then to be inserted, and the heat is to be applied in the manner prescribed above for the dynamite heat test, and the sample tested as to withstand exposure to 160° Fahr. for a period of ten minutes, before producing a discoloration of the test papers corresponding in tint to the standard colour test which is employed for governing the results of the dynamite heat test.

Testing Gun-cotton, Schultze Gunpowder, E. C. Powder, and other Explosives of the 2nd Division of the Nitro-compound Class.

A.—Compressed Gun-cotton, Tonite, &c., &c.

Sufficient material to serve for two or more tests is removed from the centre of the cartridge by gentle scraping, and, if necessary, further reduced by rubbing between the fingers.

The fine powder thus produced is spread out in a thin layer upon a paper tray 6 inches by 4½ inches, which is then placed inside a water oven, kept, as nearly as possible, at 120° Fahr.

The wire gauze shelves in the oven should be about 3 inches apart. The sample is allowed to remain at rest for fifteen minutes in the oven, the door of which is left wide open.

After the lapse of fifteen minutes the tray is removed and exposed to the air of the room for two hours, the sample being at some point within that time rubbed upon the tray with the hand, in order to reduce it to a fine and uniform state of division.

Application of the Test.—The cover of the water bath is fitted with the gas regulator which is inserted through the centre hole (No. 4). The thermometer is fixed into hole No. 3. The water in the bath is then heated to 150° Fahr., and the regulator set to maintain that temperature.

Twenty grains of the sample to be tested are weighed out, placed in the test tube, and gently pressed down until the specimen occupies a space of as nearly as possible $1\frac{5}{16}$ inch in a test tube of the dimensions specified.

A test paper is affixed to the hook of the glass rod or tube, and moistened by touching the upper edge with a drop of distilled water containing 50 per cent. of Price's glycerine. The quantity of liquid used must be only sufficient to moisten about half of the paper.

The cork carrying the rod and test paper is then fixed into the test tube, and the latter inserted into the bath to a depth of 2½ inches, measured from the cover, the regulator and thermometer being inserted to the same depth. The test paper is to be kept near the top of the test tube, but clear of the cork, until the tube has been immersed for about five minutes.

A ring of moisture will about this time be deposited upon the sides of the test tube a little above the cover of the bath; the glass rod must then be lowered until the lower margin of the moistened part of the paper is on a level with the bottom of the ring of moisture in the tube; the paper is now closely watched.

The test is complete when a very faint brown coloration makes its appearance at the line of boundary between the dry and moist parts of the paper.

The interval of time between the first insertion of the tube containing the sample of gun-cotton in the water at 150° and the first appearance of discoloration on the paper constitutes the test, and this interval of time must be *not less* than ten minutes, or the sample will not be accepted as properly purified.

B.—Schultze Powder, E. C. Powder, Collodion-Cotton, &c., &c.

Sufficient of the sample, without further mechanical division, is dried in the oven as above, and then exposed for two hours to the air. The test as directed above for compressed gun-cotton, &c., is then applied, the minimum duration of test being the same, viz. ten minutes.

Exudation and Liquefaction Test for Blasting-Gelatine, Gelatine-Dynamite, and Analogous Preparations.

Test for Liquefaction.—A cylinder of blasting-gelatine is to be cut from the cartridge to be tested, the length of the cylinder to be about equal to its diameter, and the ends being cut flat.

The cylinder is to be placed on end on a flat surface without any wrapper, and secured by a pin passing vertically through its centre.

In this condition the cylinder is to be exposed for 144 consecutive hours (six days and nights) to a temperature ranging from 85° to 90° Fahrenheit (inclusive), and during such exposure the cylinder shall not diminish in height by more than one-fourth of its original height, and the upper cut surface shall retain its flatness and the sharpness of its edge.

Note.—If the blasting-gelatine and the gelatine-dynamite to be tested be not made up in a cylindrical form, the above test is to be applied with the necessary modifications.

Test for Liability of Exudation.—There shall be no separation from the general mass of the blasting-gelatine or gelatine-dynamite of a substance of less consistency than the bulk of the remaining portion of the material, under any conditions of storage, transport, or use, or when the material is subjected three times in succession to alternate freezing and thawing, or when subjected to the liquefaction test hereinbefore described.

APPENDIX C.

APPLICATIONS FOR AUTHORISATION OF EXPLOSIVES.—INSTRUCTIONS ISSUED BY THE HOME OFFICE.

HOME OFFICE,
WHITEHALL, S.W.

Memo.]

EXPLOSIVES ACT, 1875.

(38 Vict. cap. 17.)

When an inventor desires a new explosive to be placed on the list of "Authorised Explosives," with a view to its being ultimately licensed for manufacture or importation, the steps to be taken are as follows:—

(*a*) The inventor (or his agent) must write stating (confidentially if preferred) the exact composition of the explosive he proposes to submit,* and the name by which it is to be distinguished.

This done, the applicant will be informed as to the amount of fee payable for the examination of the same under the scale of fees laid down by the Secretary of State. This fee will then have to be deposited at the Home Office, and will *not* be returned whether the result of the examination is or is not favourable to the introduction of the explosive.

(*b*) The inventor will then be asked to submit samples (the

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* A copy of the Patent Specification should be sent where practicable.

required amount being stated), and when he reports them ready a special permit for their conveyance will be sent to him.*

(*c*) The general result of the examination will be communicated to the inventor. If it is found that the explosive is likely to be reasonably safe under ordinary conditions of manufacture, transport, and use, and especially that it is not too sensitive to friction or percussion, or a combination of these, an application for a license to manufacture or import the same, will be entertained.

If, however, the explosive fails to comply with the above conditions, it will not be placed on the list of Authorised Explosives.

V. D. MAJENDIE, COLONEL,
Chief Inspector of Explosives.

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* When the samples have to be imported from abroad, an Importation License will be required.

APPENDIX D.

THE EXPLOSIVES ACT, 1875.

(38 Vict. c. 17.)

In the following abstract of this enactment, either the substance or (in many cases) the full text is given of those portions of the Act which it will be useful for manufacturers, vendors, and users of high explosives, or importers or carriers of those substances, to have at hand for reference.

The Act—which is intituled, "An Act to amend the Law with respect to manufacturing, keeping, selling, carrying, and importing Gunpowder, Nitro-glycerine, and other explosive substances"—was passed 14th June, 1875, and came into operation on 1st January, 1876. There is no occasion to notice here those sections of the Act which made temporary provision concerning factories or stores for explosives existing when the Act was passed and authorised under previous Acts; and the provisions of the Act (Part I.) which relate to gunpowder will be set out here in those cases only in which the same provisions are subsequently applied by the Act (Part II.) to high explosives.

In many of its provisions, the requirements of the Act are not easily followed, but on this point the remarks of *Sir Frederick Abel* will commend themselves :—" It can hardly be doubted that the somewhat complicated machinery of the Act, found necessary in the first instance in order to attain an efficient control over the making, carriage, keeping, &c., of all explosive substances in their great variety of forms and applications, from barrels of powder and ship-loads and stores of dynamite, ammunition, and detonators, to drawing-room fireworks, substitutes for pigeon-shooting, and toy crackers, will in due course be much simplified. There can be no doubt that the action of manufacturers and vendors themselves will importantly contribute (and has, indeed, already to some extent contributed) to such simplification, not by their raising difficulties and entertaining or conniving at attempts of evasion, but by their ready adoption of obviously wise precautions and improvements, and by the systematic exercise of care and vigilance within their individual spheres of influence."

Definition of Explosive.

In the Act the term "explosive" is defined to mean gunpowder, nitro-glycerine, dynamite, gun-cotton, blasting powders, fulminate of mercury or of other metals, coloured fires, and "every other substance, whether similar to those above mentioned or not, used or manufactured with a view to produce a practical effect by explosion or a pyrotechnic effect"; and it also includes fog-signals, fireworks, fuzes, rockets, percussion caps, detonators, cartridges, ammunition of all descriptions, and "every adaptation or preparation of an explosive as above defined" (s. 3).

Scope of the Act.

By the Act, various powers for the control of the manufacture of explosives, and of all trafficking therein, are vested in (1) the Secretary of State (*i.e.*, in practice, the Home Secretary), who is authorised to appoint Government Inspectors of Explosives; (2) in the Local Authorities defined by the Act; and (3) in Harbour Authorities. For the effective administration of the Act, large powers of search and inquiry are given to the Government Inspectors, and (in a lesser degree) to officers of Local Authorities. Breaches of law under the Act—whether of its express provisions or of rules or bye-laws framed under it—render the offenders liable to heavy and summary penalties, and these will be found mentioned in the following pages in every case specified in the Act. Where exception may be taken by the occupier of premises licensed under the Act to the requisitions made by a Government Inspector, provision is made by the Act for a reference of the matter in dispute to arbitration. Special provision is also made for official inquiry into accidents occurring with explosives, not only in a factory, magazine, or store licensed under the Act, but on any "carriage, ship, or boat" used for conveying explosives; and special regulations are required to be observed at coroners' inquests on deaths resulting from accidents with explosives.

Local Authorities.

The Local Authorities for the purposes of the Act are—

In England (s. 67),

(1.) In the City of London, the court of the Lord Mayor and Aldermen;
(2.) In the Metropolis outside the City of London, the Metropolitan Board of Works*; and
(3.) In any borough not assessed to the county rate by the county justices, the Mayor, Aldermen, and Burgesses acting by the Council; but
(4.) In any harbour within the jurisdiction of a harbour authority, whether situate or not within the jurisdiction of any local authority before mentioned, the Harbour Authority, to the exclusion of any other local authority; and
(5.) In any place in which there is no local authority as above the Justices in petty sessions assembled.*

By s. 68 the Secretary of State is empowered to declare the Council of a borough assessed to the county rate, and

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* By the Local Government Act, 1888, the powers, duties, and liabilities of the Metropolitan Board of Works were transferred to the London County Council (51 & 52 Vict. c. 41, ss. 40–45); and by the same Act (s. 7) the business of county justices as Local Authorities under the Explosives Act was transferred to County Councils.

the Improvement Commissioners of a district, to be Local Authorities (but not for a harbour) under the Act.

In Scotland (s. 110),

(1.) In any borough the Magistrates and Town Council;
(2.) In any harbour within the jurisdiction of a harbour authority, whether situate or not within the jurisdiction of any local authority for a borough, the Harbour Authority, to the exclusion of any other local authority; and
(3.) In any place other than a borough or harbour the County Justices.

But by s. 115, the Secretary of State is empowered to declare the Police Commissioners of a burgh to be the Local Authority in certain cases.

In Ireland (s. 116),

(1.) In the City of Dublin, the Lord Mayor, Aldermen, and Burgesses acting by the Town Council; and
(2.) In an urban sanitary district, the Urban Sanitary Authority; but
(3.) In any harbour within the jurisdiction of a harbour authority, whether situate or not within the jurisdiction of any local authority above mentioned, the Harbour Authority, to the exclusion of any other local authority;
(4.) In any place in which there is no local authority as above defined, the Justices in petty sessions.

The expression Harbour Authority in the Act includes (s. 107) any person or body of persons claiming to be proprietor or proprietors of or intrusted with the duty or power of maintaining or regulating any harbour, and any port, haven, and estuary, or intrusted with the duty of conserving the navigation of any tidal water; and any such harbour, port, haven, estuary, tidal water, and any wharf, dock, pier, jetty, and work, and other area, whether land or water, over which the Harbour Authority have control or exercise powers, are included in the Act in the expression "harbour."

PART I.—GUNPOWDER.

Part I. of the Act comprises the sections relating to gunpowder, and contains the following provisions, these being made applicable (with certain modifications and additions) to other explosives also in subsequent sections (Part II.) of the Act :—

Manufacture and Keeping of Gunpowder.

The manufacture of gunpowder shall not, nor shall any process of such manufacture, be carried on except at a factory for gunpowder either lawfully existing or licensed under the Act; and any person who carries on any such process of manufacture, except as allowed by the Act, shall be deemed to manufacture gunpowder at an unauthorised place.

Where gunpowder is manufactured at an unauthorised place, (1) all or any part of the gunpowder or ingredients of gunpowder found in or about such place may be forfeited, and the person so manufacturing shall be liable to a penalty of 100*l.* for every day during which he so manufactures (s. 4).

Gunpowder, unless kept for private use and not for sale to an amount not exceeding thirty pounds, or in the keeping of a carrier for the purpose of conveyance in accordance with the provisions of the Act, shall not be kept at any place except in the factory in which it is manufactured; or (2) in a magazine or store either lawfully existing or licensed under the Act, or (3) in premises registered under the Act. Where gunpowder is kept in an unauthorised place, all or any part of the gunpowder found in such place may be forfeited; and the occupier of such place, and also the owner of, or other person guilty of keeping the gunpowder, shall each be liable to a penalty of 2*s.* for every pound of gunpowder so kept (s. 5).

Licensing of Factories and Magazines.

A new factory or magazine for gunpowder shall not be established except on the site and in the manner specified in a license to be granted by the Secretary of State, with the assent of the Local Authority. Detailed directions are given in the Act for obtaining such license and the requisite assent of the Local Authority (ss. 6, 7, 8).

Regulation of Factories and Magazines.

In every gunpowder factory and magazine—

(1.) The factory or magazine, or any part thereof, shall not be used for any purpose not in accordance with the license; and

(2.) The terms of the license shall be duly observed, and the manufacture or keeping or any process in or work connected with the manufacture or keeping of gunpowder shall not be carried on except in accordance with those terms; and

(3.) The factory or magazine and every part thereof shall be maintained in accordance with the license; and any material alteration in the factory or magazine by enlarging or adding to the site, or by externally enlarging or adding to any building, or by altering any mound otherwise than by enlargement, or by making any new work, shall not be made except in pursuance of an amending license granted under the Act.

In the event of any breach (by any act or default) of this section, the gunpowder or ingredients thereof in respect to which, or being in any building or machine in respect to which, the offence was committed, may be forfeited; and the occupier shall be liable to a penalty not exceeding in the case of the first offence 50*l*, and in the case of a second or any subsequent offence 100*l*., and in addition 50*l*. for every day during which such breach continues (s. 9).

The occupier of a factory shall not be deemed guilty of a breach of this section for using in a case of emergency, or temporarily, one building or part of a building in which any process of the manufacture is, under the terms of the license, carried on, for another process of the manufacture, if he do not carry on in such building or part more than one process at the same time, and if the quantity of gunpowder or ingredients thereof in such building or part do not exceed the quantity allowed to be therein, or any less quantity allowed to be in the building or part of a building in which such other process is usually carried on; and if upon such use being continued after the lapse of twenty-eight days from the first beginning of such use he send notice to a Government inspector, and the inspector do not require its discontinuance (s. 9).

In the event of any breach (by any act or default) in any factory or magazine of the general rules for gunpowder factories prescribed by the Act,* all or any part of the gunpowder or ingredients thereof in respect to which, or being in any building or machine in respect to which, the offence was committed, may be forfeited; and the occupier shall be liable to a penalty not exceeding 10*l.*, and in addition (on a second offence) 10*l.* for every day during which such breach continues (s. 10).

Every occupier of a gunpowder factory or magazine shall, with the sanction of the Secretary of State, make special rules for the regulation of the persons employed therein, and there may be annexed to any breach of such special rules penalties not exceeding forty shillings for each offence (s. 11).

Supplemental as to Factories and Magazines.

Where the occupier of a gunpowder factory or magazine desires that any alteration should be made in the terms of his license, or any material alteration made in the factory or magazine by enlarging or adding to the site or by externally enlarging or adding to any building, or by altering any mound

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* The "general rules" of sect. 10 are omitted here, as not concerning factories for high explosives (see *post*, p. 292).

otherwise than by enlargement, or by making any new work, he may apply for an amending license. If he satisfy the Secretary of State that the alteration may be properly permitted without increased risk, the Secretary of State may grant the amending license of his own authority, but otherwise the application will be dealt with as an application for a new license (s. 12).

A gunpowder factory or magazine license shall not be avoided by any change in the occupier of the factory or magazine; but notice of the name, address, and calling of the new occupier shall be sent to the Secretary of State within three months after the change, and in default such new occupier shall be liable to a penalty not exceeding 20*s.* for every week during which such default continues (s. 13).

Stores for Gunpowder.

Any person may apply to the Local Authority for a license for a gunpowder store, and if the proposed site, construction of the store, and amount of gunpowder to be stored therein are in accordance with the Order in Council (see s. 16), the license is to be granted on payment of a fee not exceeding 5*s.* (s. 15).

Her Majesty may from time to time, by Order in Council, regulate the construction and materials and fittings of gunpowder stores, prescribe the buildings and works from which gunpowder stores are to be separated, and the distances by which they are to be separated; and prescribe the maximum amount of gunpowder, not exceeding two tons, to be kept in stores, graduated according to their construction and situation and their distance from the said buildings and works (s. 16).

In the event of any breach (by any act or default) of the general rules prescribed by the Act for gunpowder stores, all or any part of the gunpowder in respect to which or being in the store when the offence was committed may be forfeited, and the occupier shall be liable to a penalty not exceeding 10*l.*, and in addition (on a second offence) 10*l.* for every day during which such breach continues (s. 17).

A store license shall be valid only for the person named in it, and shall be annually renewed by the Local Authority, at a fee not exceeding 1*s.*, and unless so renewed shall expire (s. 18).

Every occupier of a gunpowder store may, with the sanction of the Secretary of State, make special rules for the regulation of the persons employed therein, and there may be annexed to any breach of such special rules penalties not exceeding 40*s.* for each offence (s. 19).

Registered Premises.

A person desirous of registering with the Local Authority any premises for the keeping of gunpowder shall register his name and calling, as well as the premises, in such manner and on payment of such fee, not exceeding 1*s.*, as may be directed by the Local Authority, such registration to be annually renewed at a fee not exceeding 1*s.*

In the event of any breach (by any act or default) of the general rules prescribed by the Act for registered premises, all or any part of the gunpowder in respect to which, or being in any house, building, place, safe, or receptacle in respect to which, the offence was committed may be forfeited, and the occupier shall be liable to a penalty not exceeding 2*s.* for every pound of gunpowder in respect of which or being on the premises in which the offence was committed (s. 22).

Supplemental Provisions.

The occupier of every factory, magazine, store, and registered premises for gunpowder, and every person employed in or about the same, shall take all due precaution for the prevention of accidents by fire or explosion, and for preventing unauthorised persons having access thereto or to the gunpowder therein, and shall abstain from any act whatever which tends to cause fire or explosion and is not reasonably necessary for the work therein; and any breach (by any act or default) of this section shall be deemed to be a breach of general rules (s. 23).

The Local Authority shall cause registers to be kept of all store licenses granted by and of all premises registered with them under the Act; and a ratepayer within the area of the Local Authority, or a licensee or person registered under the Act, upon payment of a fee of one shilling, and a Government inspector, or an officer appointed by any Local Authority for the purposes of the Act, or an officer of police, without payment, shall be entitled at all reasonable times to inspect and take extracts from any such registers (s. 28).

If the occupier of a store or registered premises dies or becomes bankrupt, or has his affairs liquidated by arrangement, or becomes mentally incapable or otherwise disabled, the person carrying on the business of such occupier shall not be liable to any penalty for acting under the license or registration during such reasonable time as may be necessary to allow him to obtain a fresh license or registration (s. 29).

Sale of Gunpowder.

Gunpowder shall not be hawked, sold, or exposed for sale upon any highway, street, public thoroughfare, or public place; and (1) any person hawking, selling, or exposing gunpowder for sale shall be liable to a penalty not exceeding 40*s.*, and (2) all or any part of the gunpowder so hawked or exposed for sale, or found in the possession of any person convicted hereunder may be forfeited (s. 30).

Gunpowder shall not be sold to any child apparently under the age of thirteen years; and any person selling gunpowder in contravention of this section shall be liable to a penalty not exceeding 5*l.* (s. 31).

All gunpowder exceeding one pound in weight, when publicly exposed for sale or sold, shall be in a substantial case, bag, canister, or other receptacle made and closed so as to prevent the gunpowder from escaping, and to such outermost receptacle shall be affixed the word "gunpowder" in conspicuous characters by means of a brand or label, or other mark; and if any gunpowder is sold or exposed for sale in contravention of this section the person offending shall be liable to a penalty of 40*s.*, and all or any part of the gunpowder so exposed for sale may be forfeited (s. 32).

Conveyance of Gunpowder.

The following general rules shall be observed with respect to the packing of gunpowder for conveyance:

(1.) The gunpowder, if not exceeding five pounds in amount, shall be contained in a substantial case, bag, canister, or other receptacle, made and closed so as to prevent the gunpowder from escaping; and

(2.) The gunpowder, if exceeding five pounds in amount, shall be contained either in a single package or a double package. A single package shall be a box, barrel, or case of such strength, construction, and character as may be for the time being approved by the Government inspector as being of such strength, construction, and character that it will not be broken or accidentally opened, or become defective or insecure whilst being conveyed, and will not allow the gunpowder to escape. If the gunpowder is packed in a double package the inner package shall be a substantial case, bag, canister, or other receptacle made and closed so as to prevent the gunpowder from escaping, and the outer package shall be a box, barrel, or case of wood or metal or other solid material, and shall be of such strength, construction, and character that it will not be broken or accidentally opened, or become defective or insecure whilst being conveyed, and will not allow the gunpowder to escape; and

(3.) The interior of every package, whether single or double, shall be kept free from grit and otherwise clean; and

(4.) Every package, whether single or double, when actually used for the package of gunpowder, shall not be used for any other purpose; and

(5.) There shall not be any iron or steel in the construction of any such single package or inner or outer package, unless the same is effectually covered with tin, zinc, or other material; and

(6.) The amount of gunpowder in any single package, or if there is a double package in any one outer package, shall not exceed one hundred pounds, except with the consent of and under conditions approved by a Government inspector; and

(7.) On the outermost package there shall be affixed the word "gunpowder" in conspicuous characters by means of a brand or securely attached label or other mark.

In the event of any breach (by any act or default) of any of the above-mentioned general rules, the gunpowder in respect of which the breach is committed may be forfeited, and the person guilty of such breach shall be liable to a penalty not exceeding 20*l.*

The general rules contained in this section may from time to time be altered by the Secretary of State (s. 33).

Bye-Laws.

Every Harbour Authority shall, with the sanction of the Board of Trade, make bye laws for regulating the conveyance, loading, and unloading of gunpowder within its jurisdiction.

For breaches of such bye-laws, penalties are authorised by the Act, not exceeding 20*l.* for each offence, and 10*l.* for each day during which the offence continues, besides forfeiture of all or any part of the gunpowder in respect of which, or found in the ship, boat, or carriage in respect of which, the breach of bye-law has taken place (s. 34).

Any person resisting a harbour-master or officer acting under such bye-laws shall be liable to the same penalties as a person for obstructing the harbour-master in the execution of his duty (s. 34).

On any part of the coast of the United Kingdom or in any tidal water for which there is no harbour authority, the Board of Trade are empowered by the Act to make bye-laws for that part or water as if it were a harbour and they were the harbour authority; and they may by such bye-laws define the area within which they are to be observed, and the officers by whom they are to be enforced (*ibid*).

Every railway or canal company over whose railway or canal any gunpowder is to be carried, shall, with the sanction of the Board of Trade, make bye-laws for regulating the conveyance, loading, and unloading of such gunpowder (s. 35).

Penalties for any breach of any such bye-laws may be imposed, and may be graduated according to the gravity of the offence, and according as it may be a first, second, or other subsequent offence, that is to say, pecuniary penalties not exceeding 20*l*. for each offence, and 10*l*. for each day during which the offence continues, besides forfeiture of all or any part of the gunpowder in respect of which, or being in the carriage, ship, or boat or train of carriages, ships, or boats in respect of which, the breach of bye-law has taken place (*ibid*).

The occupier of every wharf or dock on or in which gunpowder is loaded or unloaded (if such loading or unloading is not otherwise subject to any bye-laws under this Act) may, and if so required by the Secretary of State shall, from time to time, with the sanction of the Secretary of State, make bye-laws for regulating the loading and unloading of gunpowder on or in such wharf or dock, and in particular for declaring or regulating all or any of the matters which can be declared or regulated in the case of any wharf or dock within the jurisdiction of a harbour authority by bye-laws made by such authority in pursuance of this Act; and penalties may be annexed to breaches of such bye-laws, as in the case of bye-laws made under section 35 (s. 36).

The Secretary of State is empowered to make bye-laws for regulating the conveyance, loading, and unloading of gunpowder by land or otherwise, in any case in which bye-laws made under any other provision of the Act do not apply; and penalties may be annexed to any breach of any such bye-laws as in the case of bye-laws made under the thirty-fifth section (s. 37).

Any recommendation to Her Majesty in Council, any general rules with respect to packing, and any bye-laws which is or are proposed to be made under the Act by a Secretary of State or the Board of Trade shall, before being so made, be published in such manner as the Secretary of State or the Board of Trade may direct, and the bye-laws framed by any Railway Company, Canal Company, or Harbour Authority under the Act shall, before being sanctioned by the Board of Trade, be likewise published in such manner as the Board may direct (s. 38).

PART II.—EXPLOSIVES OTHER THAN GUNPOWDER.

Part II. of the Act relates to explosives other than gunpowder, and by s. 39 it is declared that, subject to the provisions hereafter in this part of the Act contained, Part I. of the Act relating to gunpowder shall apply to every other description of explosive, in like manner as if those provisions were re-enacted with the substitution of that description of explosive for gunpowder.

Modification of Part I. as applied to Explosives other than Gunpowder.

In the case of explosives other than gunpowder, the following modifications and additions are to be made in and to Part I. of the Act:

(1.) The draft license for a factory or magazine submitted by an applicant to the Secretary of State shall specify such particulars as the Secretary of State may require;

(2.) The prescribed general rules [*i.e.*, rules prescribed by an Order in Council] shall be substituted for the general rules in Part I. of the Act relating to factories, magazines, stores, and registered premises respectively; but no such general rule shall require the removal of any building or work in use at the date of the Order in Council by which such rule is made;

(3.) The Secretary of State may from time to time alter the general rules relating to packing contained in Part I. of the Act for the purpose of adapting the same to the packing of any explosive other than gunpowder; and

(4.) For the maximum amount limited by the Act to be kept for private use and not for sale, or in a store, and for the minimum amount limited by the Act to be exposed for sale or sold otherwise than in a substantial case, box, canister, or other receptacle as therein mentioned, there shall be substituted in the case of explosives other than gunpowder the following amounts; namely, (*a*) where such explosive consists of safety cartridges made with gunpowder, an amount containing not more than five times the maximum or minimum amount of gunpowder, as the case may be, above mentioned; and (*b*) in the case of any other explosive, the prescribed amount; and

(5.) Two or more descriptions of explosives shall not be kept in the same store or registered premises, except such descriptions as may be prescribed in that behalf; and, when so kept, shall be kept subject to the prescribed conditions and restrictions; and

(6.) Where any explosive, other than gunpowder, is allowed to be kept in the same store or registered premises with gunpowder, the maximum amount of gunpowder to be kept therein shall be the prescribed amount in lieu of the amount fixed by Part I. of the Act; and

(7.) Where any explosive, other than gunpowder, is allowed to be kept in the same magazine, store, or registered premises with gunpowder, the prescribed general rules shall be observed instead of the general rules set out in the Act; and

(8.) There shall be on the outermost package containing the explosive in lieu of the word "gunpowder" the name of the explosive, with the addition of the word "explosive," and if such name is materially false the person selling or exposing for sale such explosive, and also the owner of the explosive, shall be liable to a penalty not exceeding 50*l.*

(9.) With respect to the importation from any place out of the United Kingdom of either dynamite or gun-cotton, or any explosive (other than gunpowder, cartridges made with gunpowder, percussion caps, fireworks, and any prescribed explosive), the following provisions shall have effect: (*a.*) The owner and master of any ship having on board any such explosive shall not permit the same to be unloaded and delivered to any person who does not hold an importation license from the Secretary of State, and any transhipment shall be deemed to be delivery; (*b*) the Secretary of State may grant an importation license for any such explosive, and may annex thereto such provisions and restrictions as he may think fit, for the protection of the public from danger; (*c*) the license shall be of such duration as the Secretary of State may fix, and shall be available only for the person named in the license; (*d*) in the event of any breach by any act or default of the provisions of this section with respect to the importation of an explosive, or of the provisions of any importation license, all or any part of the explosive with respect to which such breach is committed, or being in any ship or boat in connexion with which such breach is committed, may be forfeited, and the owner and master of such ship or boat, and the licensee or person to whom the explosive is delivered, shall each be liable to a penalty not exceeding 100*l.*, and to a further penalty not exceeding 2*s.* for every pound of such explosive; and (*e*) the Commissioners of Customs and their officers shall have the same power with respect to any such explosive, and the ship containing the same, as they have for the time being with respect to any article on the importation of which restrictions are for the time being imposed by law (s. 40).

Nothing in the Act shall apply to the filling or conveying, for private use and not for sale, of any safety cartridges to the amount allowed by the Act to be kept for private use (s. 41).

Sect. 29 of the Passengers Act, 1855,* and sects. 23 to 27, both inclusive, of the Merchant Shipping Act, 1873,† shall apply to every explosive within the meaning of this Act in like manner as they apply to gunpowder (s. 42).

Specially dangerous Explosives.

Her Majesty from time to time, by Order in Council, may prohibit, either absolutely, or except in pursuance of a license of the Secretary of State under this Act, or may subject to conditions or restrictions the manufacture, keeping, importation from any place out of the United Kingdom, conveyance, and sale, or any of them, of any explosive which is of so dangerous a character that it is expedient for the public safety to make such Order; and any explosive manufactured or kept in contravention of any such Order shall be deemed to be manufactured or kept in an unauthorised place, and any explosive con-

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* By which gunpowder is prohibited as cargo on a passenger ship.

† Imposing a penalty of 500*l.* on any person who sends by ship "dangerous goods" under a false description, and empowering the shipowner or master to throw such goods overboard, and declaring dangerous goods so sent liable to forfeiture.

veyed in contravention of any such Order shall be deemed to be conveyed in contravention of a bye-law under the Act.

If any explosive is imported or sold in contravention of any such Order, (1) all or any part of such explosive may be forfeited; (2) the owner or master of the ship in which it was imported shall be liable to a penalty not exceeding 10*s.* for every pound of such explosive brought in the ship; and (3) the person to whom it was delivered and the person selling the same shall be liable to a penalty not exceeding 10*s.* for every pound of such explosive delivered or sold or found in his possession.

The Commissioners of Customs and their officers shall have the same power with respect to any such explosive, and the ship containing the same, as they have for the time being with respect to any article prohibited by law to be imported (s. 43).

Provisions in favour of certain Manufacturers and Dealers.

The occupier of a factory for any explosive shall not be required to take out a factory license for making up on such factory the explosive made thereon into cartridges or charges for cannon or blasting not containing within themselves their own means of ignition; and the occupier of any magazine, store or registered premises for keeping any explosive may keep such explosive when so made up into cartridges or charges as if it were not so made up (s. 44).

The occupier of a factory for any explosive who manufactures a new form of explosive similar to the one specified in his license, shall not deemed to have manufactured the same in an unauthorised place if the manufacture be on a small scale, and exclusively for the purpose of trial and not for sale, and if he send notice thereof as soon as manufactured to the Secretary of State (s. 45).

The occupier of a magazine, store, or registered premises for any explosive shall not be required by the Act to take out a factory license by reason that in connexion with such magazine, store, or premises he fills for sale or otherwise any cartridge for small arms with the said explosive, so that he observe the following regulations; namely, -

(1.) There shall not be in the room in which such filling is being carried on more than five pounds of gunpowder, or the prescribed amount of any other explosive, except it is made up into safety cartridges; and

(2.) Any work unconnected with the making of the cartridges shall not be carried on in the room while such filling is being carried on; and

(3.) There shall not be in the room while such filling is being carried on any fire nor any artificial light, except a light of such construction, position, or character as not to cause any danger of fire or explosion; and

(4.) In the case of a magazine or store, the room in which the filling is carried on shall be detached from the magazine or store, but in the immediate neighbourhood thereof, and at such distance therefrom as may be specified in the case of a magazine by the license, and in the case of a store by an Order in Council relating to stores; and

(5.) The occupier shall give notice in the case of a magazine to the Secretary of State, and in the case of a store or registered premises to the local authority, that he intends to carry on such filling of cartridges.

In the case, however, of magazine or store for which a continuing certificate has been obtained the previous consent of the Secretary of State will be required.

The regulations in this section shall be deemed to be general rules under the Act, and the breach of them shall be punished accordingly (s. 46).

The occupier of any magazine or store for any explosive shall not be required by the Act to take out a factory license by reason that, in connexion with such magazine or store, he, by filling cartridges, making charges, drying, sifting, fitting, or otherwise, adapts or prepares the said explosive for use exclusively in his mine or quarry, or in some excavation or work carried on by him or under his control, so that he observe the following regulations; namely,

(1.) There shall not be in the workshop in which such adaptation or preparation is carried on more than one hundred pounds of gunpowder or the prescribed amount of any other explosive; and

(2.) Any work unconnected with such adaptation or preparation shall not be carried on in the said workshop while such adaptation or preparation is being carried on; and

(3.) The said workshop shall be detached from the magazine or store, but in the immediate neighbourhood thereof, and at such distance therefrom as may be specified, in the case of a magazine by the license, and in the case of a store by an Order in Council relating to stores; and

(4.) An explosive of one description shall not be converted into an explosive of another description, and shall not be unmade or resolved into its ingredients; and

(5.) The occupier shall give notice in the case of a magazine to the Secretary of State, and in the case of a store to the local authority, that he intends to carry on such adaptation or preparation as is allowed by this section.

In the case, however, of a magazine or store for which a continuing certificate has been obtained, the previous consent of the Secretary of State will be required.

The regulations in this section shall be deemed to be general rules under the Act, and the breach of them shall be punished accordingly (s. 47).

Existing Factories, Magazines, and Stores.

In any continuing certificate for a lawfully existing factory or magazine for any explosive other than gunpowder, the following regulations are to form part of the terms of such certificate:

(1.) If the factory or magazine is for dynamite or any substance having nitro-glycerine as one of its component parts or ingredients, the conditions contained in the existing license, with such modifications (if any) as the Secretary of State may think necessary in order to bring the same into conformity with this Act, and also any limitation of time for the expiration of the license contained in the existing license, and also the existing power of the Secretary of State to revoke the license; and

(2.) In any other case, such terms as the Secretary of State may think expedient, having regard to the conditions (if any) contained in the license under which the factory or magazine is established; and such terms shall include any limitation of time contained in such license, but shall not require the removal of any lawfully existing building or work (s. 51).

PART III.—ADMINISTRATION OF LAW.

Government Inspectors of Explosives.

A Government inspector shall have power to make such examination and enquiry as may be necessary to ascertain whether the Act is complied with, and for that purpose (1) he may enter, inspect, and examine any factory, magazine, or store of any explosive, and every part thereof, at all times by day and night, but so as not to unnecessarily impede or obstruct the work in such factory, magazine, or store, and may make inquiries as to the observance of the Act and all matters and things relating to the safety of the public or of the persons employed in or about such factory, magazine, or store; (2) he may enter, inspect, and examine any premises registered under this Act, and every part thereof, in which any explosive is kept, or is reasonably supposed by him to be kept, at all reasonable times by day; and (3) he may require the occupier of any factory, magazine, store, or premises which he is entitled, under this section, to enter, or a person employed by such occupier therein, to give him samples of any explosive or ingredients of an explosive therein, or of any substance therein, the keeping of which is restricted or regulated by the Act, or of any substance therein which the inspector believes to be an explosive, or such ingredients or substance.

The occupier of every such factory, magazine, store, and registered premises, his agents and servants, shall furnish the means required by the inspector as necessary for every such entry, inspection, examination, and inquiry.

Any person who obstructs an inspector in the execution of his duties under the Act shall be liable to a penalty of 100*l.* for each offence (s. 55).

If in any matter not expressly provided for by the Act, an inspector find any factory, magazine, or store for an explosive, or any part thereof, or any thing or practice therein or connected therewith, to be unnecessarily dangerous or defective, so as in his opinion to tend to endanger the public safety or the bodily safety of any person, such inspector may require the occupier of such factory, magazine, or store to remedy the same; and where the occupier objects to comply with the requisition he may require the matter to be referred to arbitration in manner provided by the Act (s. 56).

Accidents.

Whenever there occurs any accident by explosion or by fire in or about or in connexion with any factory, magazine, or store, or any accident by explosion or by fire causing loss of life or personal injury in or about or in connexion with any registered premises, the occupier of such factory, magazine, store, or premises shall forthwith send or caused to be sent notice of such accident and of the loss of life or personal injury (if any) occasioned thereby to the Secretary of State. A notice of any accident of which notice is sent in pursuance of this section to a Government inspector need not be sent to any inspector or sub-inspector of factories or any inspector of mines.

Where in, about, or in connexion with any carriage, ship, or boat, either conveying an explosive, or on or from which an explosive is being loaded or unloaded, there occurs any accident by explosion or by fire causing loss of life or personal injury, or if the amount of explosive conveyed or being so loaded or unloaded exceeds in the case of gunpowder half a ton, and in the case of any other explosive the prescribed amount, any accident by explosion or by fire, the owner or master of such carriage, ship, or boat, and the owner of the explosive conveyed therein or being loaded or unloaded therefrom, or one of them, shall forthwith send or cause to be sent notice of such accident, and of the loss of life or personal injury, if any, occasioned thereby, to the Secretary of State.

Every such occupier, owner, or master as aforesaid who fails to comply with this section shall be liable to a penalty of 20*l.* (s. 63).

Where an accident by explosion or fire has occurred in, and wholly or partly destroyed a factory magazine, or any magazine or store, the factory magazine, magazine, or store shall not be reconstructed, and any further supply of an explosive shall not be put therein, except with the permission of the Secretary of State; and where an accident by explosion or fire in a factory has wholly or partly destroyed any building of such factory as to which a Government inspector has previously to the accident sent to the occupier a notice that the building is unduly near to some building or work outside the factory, such building shall be reconstructed only upon such site in the factory and with such precautions as may seem reasonable to the Secretary of State: and where an accident by explosion or by fire in a factory has wholly or partly destroyed two or more buildings in such factory, not more than one of such buildings shall be reconstructed except with the permission of the Secretary of State; provided that this enactment shall not apply to any buildings in a lawfully existing factory, if either both or all such buildings are incorporating mills, or if as regards any other buildings a Government inspector has not previously to the accident sent to the occupier a notice that such buildings are unduly near to each other. The reconstruction of any building in contravention of this section shall be deemed to be a breach of the terms of the license, and shall be punished accordingly (s. 64).

Coroners' Inquests.

Where a coroner holds an inquest upon a body of any person whose death may have been caused by any accident of which notice is required by the Act to be given to the Secretary of State, or by the explosion of any explosive, the coroner is to adjourn such inquest unless a Government inspector, or some person on behalf of the Secretary of State, is present to watch the proceedings; but if such accident or explosion has not occasioned the death of more than one person, and the coroner has sent to the Secretary of State not less than forty-eight hours' notice of the time and place of holding the inquest, it shall not be imperative on him to adjourn such inquest if the majority of the jury think it unnecessary; and where evidence is given at an inquest at which no Government inspector or official is present, of any neglect as having caused or contributed to the explosion or accident, or of any defect in or about or in connexion with any factory, magazine, store, or registered premises, or any carriage, ship, or boat carrying an explosive, appearing to the coroner or jury to require a remedy, the coroner is to send to the Secretary of State notice in writing of such neglect or defect (s. 65).

Special Inquiries.

The Secretary of State may direct an inquiry to be made by a Government inspector into the cause of any accident which is caused by an explosion or fire either in connexion with any explosive, or of which notice is required by the Act to be given to the Secretary of State; and where it appears to the Secretary of State, either before or after the commencement of any such inquiry, that a more formal investigation of the accident, and of the causes and circumstances thereof, is expedient, the Secretary of State is empowered to direct such an investigation to be held by a court having all the powers of a court of summary jurisdiction hearing informations for offences against the Act, as well as the powers of a Government inspector under the Act, and the special powers of entry and inspection of premises, of summoning witnesses, and of calling for books, papers, and documents, which are given by the Act (s. 66).

Powers of Officer of Local Authority.

Any officer authorised by the local authority may, on producing, if demanded, either a copy of his authority purporting to be certified by the clerk or some member of the local authority, or some other sufficient evidence of his authority, require the occupier of any store (not being subject to the inspection under the Act of any Inspector of Mines) or any registered premises, or any small firework factory, to show him every or any place and all or any of the receptacles in which any explosive or ingredient of an explosive, or any substance the keeping of which is restricted or regulated by the Act, that is in his possession is kept, and to give him samples of such explosive, ingredient, or substance, or of any substance which the officer believes to be an explosive or such ingredient or substance.

Any occupier of a store or registered premises or a small firework factory who refuses to comply with any such requisition of an officer of the local authority, or to give him such assistance as he may require for the purpose of this section, or who wilfully obstructs the local authority, or any officer of the local authority, in the execution of the Act, shall be liable to a penalty of 20*l.* (s. 69).

Local Authority may provide Carriages and Magazines.

Every harbour authority and canal company shall, in addition to any other powers they may have for the like purpose, have power to provide carriages, ships, and boats for the conveyance, loading, or unloading of an explosive within the jurisdiction of such authority or company, and may charge a reasonable sum fixed by a bye-law under the Act for the use of such carriage, ship or boat (s. 71).

General Power of Search.

Where any of the following officers—namely, any Government inspector, or any constable or any officer of the local authority, if such constable or officer is specially authorised either (*a*) by a warrant of a justice (which warrant such justice may grant upon reasonable ground being assigned on oath), or (*b*) (where it appears to a superintendent or other officer of police of equal or superior rank, or to a Government inspector, that the case is one of emergency and that the delay in obtaining a warrant would be likely to endanger life), by a written order from such superintendent, officer, or inspector,—has reasonable cause to believe that any offence has been or is being committed with respect to an explosive in any place (whether a building or not, or a carriage, boat, or ship), or that any explosive is in any such place in contravention of the Act, or that the provisions of the Act are not duly observed in any such place, such officer may, on producing, if demanded, in the case of a Government inspector a copy of his appointment, and in the case of any other officer his authority, enter at any time, and if needs be by force, and as well on Sunday as on other days, the said place, and every part thereof, and examine the same, and search for explosives therein, and take samples of any explosive and ingredient of an explosive therein, an any substance reasonably supposed to be an explosive, or suc ingredient which may be found therein.

Any person who, by himself or by others, fails to admit int any place occupied by or under the control of such person any officer demanding to enter in pursuance of this section, or i any way obstructs such officer in the execution of his duty under this section, shall be liable to a penalty of 50*l.*, and shal also be liable to forfeit all explosives, and ingredients thereof which are at the time of the offence in his possession or unde his control at the said place.

Where a constable or officer of the local authority speciall authorised by written authority other than a warrant of Justice of the Peace, enters and searches as above provided, special report in writing of every act done by such constabl or officer in pursuance of that authority, and of the grounds o which it is done, shall be forthwith sent by the person b whom or under whose authority it was done to the Secretary o State (s. 73).

Where any of the following officers—namely, any Government inspector, or any constable, or any officer of the loc authority—has reasonable cause to believe that any explosiv or ingredient of an explosive or substance found by him is liable to be forfeited under the Act, he may seize and detai the same until some Court of Summary Jurisdiction has determined whether the same is or is not so liable to be forfeited, and with respect thereto the following provisions shall have effect:

(1.) The officer seizing may either require the occupier of the place in which it was seized (whether a building or not, or a carriage, boat, or ship) to detain the same in such place or in any place under the control of such occupier, or may remove it in such manner and to such place as will in his opinion least endanger the public safety, and there detain it, and may, where the matter appears to him to be urgent and fraught with serious public danger, and he is a Government inspector, or is authorised by an order from a Government inspector or a Justice of the Peace, or from a superintendent or other officer of police of equal or superior rank, cause the same to be destroyed or otherwise rendered harmless; but before destroying or rendering harmless the same he shall take and keep a sample thereof, and shall, if required, give a portion of the sample to the person owning the explosive, or having the same under his control at the time of the seizure; and any such occupier who, by himself or by others, fails to keep the same when he is required in pursuance of this section to detain it, and any such occupier or other person who, except with the authority of the officer seizing the same, or of a Government inspector, or in case of emergency for the purpose of preventing explosion or fire, removes, alters, or in any way tampers or deals with the same while so detained, shall be liable to a penalty not exceeding 50*l.*, and shall also be liable to forfeit all explosives, and ingredients thereof, which are at the time of the offence in his possession or under his control at the said place;

(2.) The proceedings before a Court of Summary Jurisdiction for determining whether the same is or is not liable to forfeiture shall be commenced as soon as practicable after the seizure; and

(3.) The receptacles containing the same may be seized, detained, and removed in like manner as the contents thereof; and

(4.) The officer seizing the same may use for the purposes of the removal and detention thereof any ship, boat, or carriage in which the same was seized, and any tug, tender, engine, tackle, beasts, and accoutrements belonging to or drawing or provided for drawing such ship, boat, or carriage, and shall pay to the owner a reasonable compensation for such use, to be determined, in case of dispute, by a Court of Summary Jurisdiction, and to be recovered in like manner as penalties under the Act; and

(5.) The same shall, so far as practicable, be kept and conveyed in accordance with the Act, and with all due precaution to prevent accident, but the person seizing, removing, detaining, keeping, or conveying the same shall not be liable to any penalty, punishment, or forfeiture, or to any damages, for keeping or conveying the same, so that he use all such due precautions as aforesaid; and

(6.) The officer seizing the same, or dealing with the same in pursuance of this section, shall not be liable to damages or otherwise in respect of such seizure or dealing, or any act incidental to or consequential thereon, unless it is proved that he made such seizure without reasonable cause, or that he caused damage to the article seized by some wilful neglect or default (s. 74).

Any of the following officers—namely, any Government inspector under the Act, any chief officer of police, and any superior officer appointed for the purposes of this Act, where the justices in petty sessions are the local authority, by the court of quarter sessions to which such justices belong, and in the case of any other local authority by the local authority itself—may, for the purpose of ascertaining whether the provisions of the Act with respect to the conveyance, loading, unloading, and importation of an explosive are complied with, enter, inspect, and examine at any time, and as well on Sundays as on other days, the wharf, carriage, ship, or boat of any carrier or other person who conveys goods for hire, or of the occupier of any factory, magazine, or store, or of the importer of any explosive, on or in which wharf, carriage, ship, or boat he has reasonable cause to suppose an explosive to be for the purpose of or in course of conveyance, but so as not to unnecessarily obstruct the work or business of any such carrier, person, occupier, or importer.

Any such officer, if he find any offence being committed under the Act in any such wharf, carriage, ship, or boat, or on any public wharf, may seize and detain or remove the said carriage, ship, or boat, or the explosive, in such manner and with such precautions as appear to him to be necessary to remove any danger to the public, and may seize and detain the said explosive, as if it were liable to forfeiture.

Any officer above mentioned in this section, and any officer of police, or officer of the local authority who has reasonable cause to suppose that any offence against the Act is being committed in respect of any carriage (not being on a railway) or any boat conveying, loading, or unloading any explosive, and that the case is one of emergency, and that the delay in obtaining a warrant will be likely to endanger life, may stop, and enter, inspect, and examine such carriage or boat, and by detention or removal thereof or otherwise take such precautions as may be reasonably necessary for removing such danger, in like manner as if such explosive were liable to forfeiture.

Every officer shall for the purpose of this section have the same powers and be in the same position as if he were authorised by a search warrant granted under the Act, and any person failing to admit or obstructing such officer shall be liable to the same penalty (s. 75).

When a Government inspector, constable, or officer of the local authority takes samples of any explosive, or ingredient, or substance, he shall pay for or tender payment for the same to such amount as he considers to be the market value thereof, and the occupier of the place in which, or the owner of the bulk from which the sample was taken, may recover from the officer taking the sample, as a debt in the county court, any excess of the real value over the amount so paid or tendered, and any amount so tendered (s. 76).

PART IV.—SUPPLEMENTAL PROVISIONS.

Trespassers and Offenders.

Any person who enters without permission or otherwise trespasses upon any factory, magazine, or store, or the land immediately adjoining thereto which is occupied by the occupier of such factory, magazine, or store, or on any wharf for which bye-laws are made by the occupier thereof under the Act, shall for every such offence, if not otherwise punishable, be liable to a penalty not exceeding 5*l.*, and may be forthwith removed from such factory, magazine, store, land, or wharf, by any constable, or by the occupier of such factory, magazine, store, or wharf, or any agent or servant of or other person authorised by such occupier.

Any person other than the occupier of or person employed in or about any factory, magazine, or store who is found committing any act which tends to cause explosion or fire in or about such factory, magazine, or store, shall be liable to a penalty not exceeding 50*l.*

The occupier of any such factory, magazine, store, or wharf shall post up in some conspicuous place or places a notice or notices warning all persons of their liability to penalties under this section; but the absence of any such notice or notices shall not exempt a person from a penalty under this section (s. 77).

Any person who is found committing any act for which he is liable to a penalty under the Act, and which tends to cause explosion or fire in or about any factory, magazine, store, railway, canal, harbour, or wharf, or any carriage, ship, or boat, may be apprehended without a warrant by a constable, or an officer of the local authority, or by the occupier of or the agent or servant of or other person authorised by the occupier of such factory, magazine, store, or wharf, or by any agent or servant of or other person authorised by the railway or canal company or harbour authority, and be removed from the place at which he is arrested, and conveyed as soon as conveniently may be before a court of summary jurisdiction.

Where any person is guilty of any offence which under the Act is punishable by a pecuniary penalty only, and which, in the opinion of the court that tries the case, was reasonably calculated to endanger public safety or to cause serious personal injury, or to cause a dangerous accident, and was committed wilfully by the person accused, such person shall be liable to six months' imprisonment, with or without hard labour (s. 78).

Every person who forges or counterfeits any license, certificate, document, or plan granted or required in pursuance or for the purposes of the Act, or gives or signs any such document or plan which is to his knowledge false in any material particular, or wilfully makes use of any such forged, counterfeit, or false license, certificate, document, or plan, shall be liable to imprisonment, with or without hard labour, for a term not exceeding two years (s. 81).

Every person who, without due authority, pulls down, injures, or defaces any notice, copy of rules, or document, when affixed in pursuance of this Act, or of the special rules, shall be liable to a penalty not exceeding two pounds (s. 82).

Legal Proceedings.

Where any offence under the Act for which the occupier of any factory, magazine, store, or registered premises is liable to a penalty or forfeiture has in fact been committed by some other person, such other person shall be liable to a penalty not exceeding twenty pounds, and the occupier shall be exempt from any penalty and forfeiture upon proving that he had used due diligence to enforce the observance of the Act, and had taken all practicable means in his power to prosecute the actual offender to conviction; and where a Government inspector, or an officer of the local authority, or the local authority, is satisfied that such occupier would, under the foregoing provisions, be exempt, and the occupier gives all facilities for proceeding against and convicting the actual offender, the inspector, officer, or local authority shall proceed against that person in the first instance, without first proceeding against the occupier.

Where any offence under the Act for which any warehouseman, carrier, occupier of a wharf or dock, or owner or master of any ship, boat, or carriage, is liable to a penalty or forfeiture, has in fact been committed by some other person, this section is to apply in like manner as in the case of an occupier (s. 87).

Where a carrier or owner or master of a ship or boat is prevented from complying with the Act by the wilful act, neglect, or default of the consignor or consignee of the explosive, or other person, or by the improper refusal of the consignee or other person to accept delivery of the explosive, such consignor, consignee, or other person who is guilty of such wilful act, neglect, default, or refusal shall be liable to the same penalty to which the carrier, owner, or master is liable for a breach of the Act, and his conviction shall exempt the carrier, owner, or master from any penalty or forfeiture under the Act (s. 88).

Where a court before whom a person is convicted of an offence against the Act has power to forfeit any explosive, the court may, if it think it just and expedient, in lieu of forfeiting such explosive, impose upon such person, in addition to any other penalty or punishment, a penalty not exceeding such sum as appears to the court to be the value of the explosive so liable to be forfeited.

Where any explosive, or ingredient of an explosive, is alleged to be liable under the Act to be forfeited, any indictment, information, or complaint may be laid against the owner of such explosive or ingredient, for the purpose only of enforcing such forfeiture; and where the owner is unknown, or cannot be found, a court may cause a notice to be advertised, stating that unless cause is shown to the contrary at the time and place named in the notice, such explosive will be forfeited, and at such time and place the court, after hearing the owner or any person on his behalf, may order all or any part of such explosive or ingredient to be forfeited (s. 89).

Every offence under the Act may be prosecuted, and every penalty under the Act recovered, and all explosives and ingredients liable to forfeiture under the Act may be forfeited, either on indictment or before a court of summary jurisdiction, provided that the penalty shall not exceed 100*l.*, exclusive of costs, and of any forfeiture or penalty in lieu of forfeiture, and the term of imprisonment shall not exceed one month. All costs and penalties may be recovered before a court of summary jurisdiction.

A court of summary jurisdiction may by order prohibit a person from doing any act for doing which such person has twice been convicted under the Act, and may order any person disobeying such summary order to be imprisoned for any period not exceeding six months (s. 91).

The court of summary jurisdiction, when hearing and determining an information or complaint, in respect of any offence under the Act, shall be constituted either of two or more justices of the peace in petty sessions, or of a magistrate empowered by law to do alone any act authorised to be done by more than one justice of the peace.

Nothing in the Act shall render liable to any penalty or forfeiture the owner or master of any ship or boat, or any carrier or warehouseman, or the person having charge of any carriage, for any act done in breach of the Act, if he prove that by reason of stress of weather, inevitable accident, or other emergency, the doing of such act was, under the circumstances, necessary and proper (s. 100).

Definition and Classification of Explosives.

Her Majesty is empowered, by Order in Council, to declare that any substance which appears to Her Majesty to be specially dangerous to life or property by reason either of its explosive properties, or of any process in the manufacture thereof being liable to explosion, shall be deemed to be an explosive within the meaning of the Act; and Her Majesty is also empowered from time to time, by Order in Council, to define, for the purposes of the Act, the composition, quality, and character of any explosive, and to classify explosives (ss. 104, 106).

Any person who carries on any of the following processes—namely, the process of dividing into its component parts or otherwise breaking up or unmaking any explosive, or making fit for use any damaged explosive, or the process of remaking, altering, or repairing any explosive, shall be subject to the provisions of this Act as if he manufactured an explosive, and the expression "manufacture" in the Act is to be construed accordingly (s. 105).

Table of Fees.

The following are to be the maximum fees for licenses and certificates granted by the Secretary of State (s. 26):—

Factory license, original	Ten pounds.
,, ,, amending	Five pounds.
,, ,, renewal when lost ..	Five shillings.
Magazine license, original	Ten pounds.
,, ,, amending	Five pounds.
,, ,, renewal when lost ..	Five shillings.
Importation license, first grant	One pound.
,, ,, renewal	Ten shillings.
Continuing certificate	Forty shillings.

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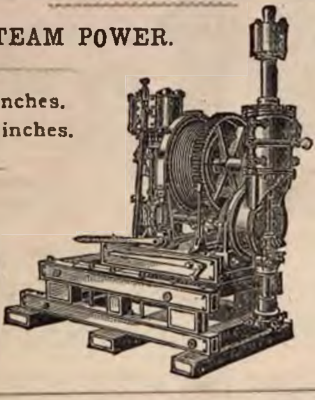

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