A PRIMER OF EXPLOSIVES

MAJOR A. COOPER-KEY

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Harry Ernst Muller,
1907

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FOR THE USE OF LOCAL INSPECTORS AND DEALERS

BY

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EDITOR'S PREFACE

THIS book, as will be seen from the title, is not intended to rank as a scientific treatise, but to give information which will assist an inspector in carrying out his duties with judgment, and a trader in applying precautions suitable to the particular explosives with which he is concerned. The expert may find nothing which is new to him in this work, but those who administer the law, and those whose business involves the handling and keeping of explosives, will probably find much in this little book which it is of advantage to them to know.

In preparing a book of this sort, a Government Inspector is restricted in two directions. He must not encourage too wide a reading of the law, and he must avoid entering into such details of the manufacture or composition of explosives as would disclose any of the numerous trade secrets which come to his knowledge. The author appears to have been skilful in overcoming both these difficulties without impairing the value of his work. J. H. T.

PREFACE

A desire has been frequently expressed by officers appointed by local authorities under the Explosives Act for some means of obtaining an elementary knowledge of the composition, methods of manufacture, and appearance of the various blasting explosives in common use, together with an authoritative pronouncement respecting any special risks attaching to the handling of particular kinds, in order that they may be in a position to deal intelligently with questions of storage and conveyance, which not only may require prompt decision, but in regard to which they are possibly compelled to call in question the conduct of traders who have spent their lives in the explosives industry, and may consequently be somewhat inclined to resent interference by non-experts.

While there is no lack of literature on the general subject of explosives, the standard works are, as a rule, either too technical or too comprehensive to meet the requirements of the officers in question, and it is hoped, therefore, that the present little volume, unpretentious as it is in scope and price, may supply a want.

In the following pages little attempt has been made to explain the law,—this has been adequately attended to in the Guide recently prepared by Captain Thomson, H.M. Chief-Inspector of Explosives, who has kindly agreed to edit this handbook,—but occasional reference to the legal aspect cannot be altogether omitted, and there are no doubt places where this work and the Guide overlap. In such cases every care has been taken to avoid ambiguity, but it is clear that in a publication which is in no sense official a slight degree of latitude in the interpretation of the letter of the law is allowable. Finally, the local inspector is strongly recommended in all cases of doubt and difficulty to apply for advice direct to H.M. Inspectors of Explosives, Home Office, Whitehall, who are only too glad to explain obscure points to the best of their ability. In order to adapt the same Act of Parliament to articles of such widely different characteristics as Christmas crackers and torpedoes, ha'porths of squibs and tons of dynamite, a large measure of elasticity is necessary, and this can only be achieved by granting the Government extensive powers of modifying and enlarging the original statute by supplementary orders with a consequent and unavoidable sacrifice of simplicity. On the whole, considering the variety and complicated nature of the substances involved, and the vast increase in their number in recent years, the Explosives Act has served its purpose remarkably well—but it cannot be said to err on the side of brevity.

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CHAPTER I

WHAT IS AN EXPLOSIVE?

Combustion.—When a candle, a lump of coal, or a jet of coal-gas burns,—that is to say, when the hydrogen and carbon, of which these substances are mainly composed, are so heated as to commence to combine with the oxygen of the air, the process is a gradual one. The air in the immediate vicinity is first utilised, and as the oxygen it contains is expended further supplies rush in, until eventually the whole of the hydrogen is converted into water (H_2O), and the carbon into carbon monoxide (CO) or carbonic acid (CO_2). But although what is commonly known as combustion is therefore an operation occupying a considerable period of time, varying according to the quantity of combustible to be oxidised, it is an exceedingly rapid progress in comparison with that which takes place when a fallen tree, for instance, perishes by decay,—although the chemical combinations and the total amount of heat evolved are practically the same, whether the elements composing the wood are oxidised by combustion or by decay.

Explosion.—Similarly, if by artificial means the natural supply of oxygen in the atmosphere is increased, combustion is rendered more rapid and consequently more violent. Now there are certain compounds which contain a considerable quantity of oxygen, with which they are very ready to part when heated, and if therefore one of these materials be very intimately mixed with a combustible, *i.e.* with a substance which is readily oxidised, so that each particle of combustible has the requisite particle of oxygen ready to hand, so to speak, and if, moreover, the proportions of the oxygen-bearing compound and of the combustible are so adjusted that both are approximately satisfied with little or no waste on either side, it is clear that combustion will be transmitted throughout the mass much more quickly than if the supply of oxygen were gradually obtained from the atmosphere.

Effect of Confinement.—But this is not all. The time taken for the heat to penetrate the mixture depends largely on the pressure, and in a bore-hole in a quarry, or in the bore of a gun where there is no free outlet for the gases formed by the combustion, a high degree of pressure is quickly set up, which increases the rate of burning, the burning in its turn increases the pressure, and so on in multiple ratio, the net result being that the whole process of combustion is completed in a period of time so short as to be inappreciable to the human senses, and the mixture is termed an explosive.

Detonation.—In the above description oxidisation, although very rapid, is assumed to have been effected by the transmission throughout the material of heat alone, and the process must therefore spread gradually from the point of ignition. It has been found, however, that by a combination of heat and shock such as is obtained by the explosion of a small charge of fulminate of mercury, explosion can in the case of many explosive materials be far more rapidly effected. These materials are known as *high* explosives, and the process is termed detonation.

Effect of Explosion.—All explosives in common use are solids, and the actual effect of firing a charge is in a moment to convert the solid into an equal weight of gas and vapour struggling to occupy a space hundreds of times greater than that occupied by the original solid. An enormous pressure is thus exerted on the surrounding material, whether it be stone or coal or merely air, and this pressure is immensely increased by the very high temperature at which the gases and vapours are produced, and may at the moment of maximum intensity amount to 100 tons per square inch or more. The effect of this pressure may be imagined when it is realised that the maximum pressure in a shot-gun is, as a rule, limited to about three tons per square inch.

Dynamite striking downwards.—And this is a good opportunity to expose the very popular fallacy that dynamite strikes downwards! The pressure exerted by the sudden conversion of dynamite into gas must of course be equal in all directions, and the fallacy probably arose in the first instance from a comparison of the apparent effects of dynamite and gunpowder. Dynamite exploded on the ground leaves a hole, or crater, as it is called; gunpowder, unless strongly confined, forms no crater; the reason being that this latter explosive is comparatively so slow in its action that there is time for it to seek out and expend its energy along lines of least resistance, *i.e.* into the atmosphere, whereas dynamite or other high explosive is so suddenly converted into gas that it has no time to do this and its energy is consequently exerted equally all round. Place a huge block of steel on a bag of gunpowder in such a manner that the line of least resistance is through the ground, and gunpowder will seem to strike downwards.

Essentials of an Explosive.—The essentials, then, of an explosive are two—a combustible and an oxygen-carrier, and with few exceptions neither of these alone is an explosive. Thus coal-gas, petroleum, which includes ordinary paraffin oil, petrol, naphtha, benzoline, etc., and acetylene (uncompressed) are merely combustible, and no more explosive than charcoal or sulphur. In the same way saltpetre, one of the commonest oxygen-carriers, is not of itself explosive. This must not be taken to imply that no possible risk of explosion is to be anticipated from the presence of any of these substances. Coal-gas and acetylene have only to be mixed with air in proper proportion to become violently explosive, and the same may be said of petroleum vapour, which by some natures of petroleum is rapidly given off at ordinary temperatures. Solid combustibles such as charcoal and sulphur must, on the other hand, be reduced to fine dust before they can lead to danger of this sort in the presence of air only, and even then this dust must be distributed in proper proportion through the atmosphere before explosion can ensue, so that the risk from these two materials may therefore be regarded as very remote. Of the oxygen-carriers chlorate of potash is the only one of those commonly met with which parts with its oxygen so readily as to lead to an explosive risk. Fires and explosions have been caused on several occasions by this substance accidentally coming in contact with organic or other combustible matter, and a few simple and obvious precautions should therefore be observed by those who find it necessary to keep it in any quantity.

An Explosive within the meaning of the Act.—Special reference has been made to the above compounds not only for the purpose of pointing out the conditions under which they become dangerous, but also on account of a somewhat commonly accepted notion that at any rate two of the commonest of them, coal-gas and petroleum, are themselves inherently explosive; but as a matter of fact none of these, even when in admixture with air, are "explosives within the meaning of the Explosives Act," since they are not "used or manufactured with a view to produce a practical effect by explosion or a pyrotechnic effect," and no further notice will consequently be taken of them. It may, however, not be amiss to point out that although there is no statutory obligation to report to the Home Office accidents caused by these materials,—any more than there is in the case of a kitchen boiler bursting,—yet the Inspectors of Explosives are always glad to receive particulars of accidents that may occur in connection with acetylene, petroleum, chlorate of potash, and similar substances.

Properties of a good Explosive.—A good blasting explosive should possess as many as possible of the following properties :—

(1) It must be reasonably safe to handle and use.

(2) If a chemical compound it must be stable, *i.e.* not liable to decompose under the extreme conditions of moisture and temperature it is likely to meet with. If a mechanical mixture the ingredients must be such that no dangerous reaction will take place between them.

(3) If the explosive contains a liquid which is itself an explosive, such as nitro-glycerine, this liquid must be so thoroughly absorbed in the solid that no exudation will take place under any climatic conditions whatever.

So far as this country is concerned these three qualifications are ensured by the tests to which all explosives are submitted by the Home Office before being authorised for manufacture or importation. An explosive which passes the tests is authorised under a specific definition in which provisions necessary to ensure chemical and physical stability are included; and failure to conform to this definition renders a consignment liable to forfeiture as an unauthorised explosive, and the owner to penalties.

(4) It should be uninjured by water.

(5) Its density should be high to enable it to be used in a bore-hole of small diameter, thus saving labour, and increasing the number of volumes of gas into which the solid is converted on explosion.

(6) It should not require a detonator to fire it, on account of the danger attached to the handling and use of these sensitive little articles.

(7) It should be plastic, or at any rate of such a nature as to be easily adapted to the shape of an irregular bore-hole.

(8) It should produce on explosion nothing more harmful than carbonic-acid gas and water. Even carbonic acid is poisonous, and it is therefore misleading and mischievous to say of any explosive that it gives off no noxious fumes; but nearly all explosives produce carbonic oxide as well, and this is a very deadly poison. Nitrous fumes also are given off by some, and those containing sulphur are always liable to produce sulphuretted hydrogen, another poisonous gas.

(9) It should be reasonably safe for use in fiery or dusty coal-mines.

(10) Last but not least, it should be cheap. In these days of strenuous competition this may almost be regarded as a *sine qua non.* An explosive may possess all the above-mentioned virtues and may be eminently suitable for some special work where expense is no object, but for general practical use an excess in price of a very few pence per lb. will put it right out of court.

Choice of an Explosive.—It is not to be supposed, however, that any one explosive can conform to all these requirements, and in making a selection regard must be had to that quality which the work in hand brings into greatest prominence. Thus for wet work use the gelatines which are unaffected by wet; for coal-getting, where a rending as opposed to a shattering action is required, gunpowder should be chosen, unless, as in a fiery or dusty mine, its use is prohibited by other and more important considerations; for driving a hard stone heading or for shaft sinking where mere removal of the material as quickly as may be is of the first importance, blasting gelatine would probably give the best results weight for weight, although possibly the considerable difference in price might render the use of gelignite cheaper per yard run, a matter greatly depending on whether hand or power driven drills are to be employed; and so on.

In the next few chapters each class of explosive as classified in the Order in Council[1] made under section 106 of the Explosives Act will be briefly discussed in turn.

[1] Order in Council No. 1.

CHAPTER II

Class I.—Gunpowder

Definition.—This class consists of one explosive only, viz. *gunpowder ordinarily so called*—a description which at the best can but be regarded as a makeshift, but was perhaps at the time the Act was framed as narrow a definition as could be generally accepted. It is, however, open to the objection that when intended for use otherwise than as a propellant, as in the case of blasting powder, commonly known as "rock" powder, or when made up into cubes or prisms for cannon, and therefore in no sense a "powder," there may well be, in the minds of local authority officers and the police, who have only the name and appearance to go by, a feeling of uncertainty as to its proper classification. On the other hand, the small-arm nitro-compounds such as Schultze, E.C., etc., which are commonly referred to as "gunpowders," are not seldom wrongly placed by these officers in Class I.

Components.—Gunpowder ordinarily so-called is a mixture in any proportions of saltpetre, sulphur, and charcoal; the mixture may be more or less thorough, according to the purpose for which the powder is required, and the mixed ingredients may be subsequently moulded or cut into any desired shape and size, but the essence of the definition is that there should be no other ingredient than these three.

Saltpetre.—Saltpetre, as understood in the gunpowder trade of this country, is nitrate of potash only, but in South America nitrate of soda or Chili saltpetre is also largely used in the manufacture of gunpowder. Both varieties occur as natural products in warm climates, but when obtained from this source have to undergo a thorough process of refining before becoming suitable for gunpowder. Nitrate of potash is also produced artificially from animal refuse in France and Germany, but in this country the chief source of supply is nitrate of soda, which is imported in large quantities for manuring purposes, and is convertible into nitrate of potash by treatment with chloride of potash. One volume of saltpetre contains as much oxygen as 3000 volumes of air.

Sulphur.—Sulphur is used in gunpowder merely to lower the igniting point of the mixture, and it is quite possible to make gunpowder without this ingredient. Refined sulphur alone should be used; the sublimed variety, commonly known as flowers of sulphur, may contain injurious acids, and should not be employed in powder manufacture.

Charcoal.—The whole character of the powder depends, however, on the third ingredient. Charcoal may be prepared in many different ways, from many kinds of wood, and the characteristics of the finished gunpowder may be infinitely varied by taking advantage of this. An experienced charcoal-burner can regulate to a nicety the proportion of hydrogen and oxygen left in the charcoal, and on this, to a great extent, depend the pressure subsequently developed in the gun and the velocity given to the shot. As regards the most suitable woods for the preparation of charcoal, dogwood, alder, willow, and straw have given the most successful results.

Proportions of each.—The proportions of the three ingredients vary according to the purposes for which the powder is to be used. In the best sporting and military small-arm powders the figures in this country are 75 parts of saltpetre, 10 of sulphur, and 15 of charcoal, whereas in common blasting powders the proportion of saltpetre is as low as 62 per cent. For reasons into which it is not necessary to enter, this reduction in the quantity of available oxygen does not proportionately diminish the efficiency of the powder for blasting purposes, but the fumes from the explosion become vastly more poisonous.

Process of Manufacture.—After being sifted to get rid of foreign matter, the ingredients, in the proper proportions, are roughly mixed in bags holding as a rule 60 or 80 lbs. and the "green" charges, as they are called, are then taken to the mills. Here they are thoroughly incorporated by means of edge runners which revolve both on vertical and horizontal axes as in the "pug mill" of the brickworks. These runners weigh about 5 tons each, and the time of "milling" varies from one hour or less in the case of blasting powders to eight or ten hours for military or best sporting. The powder is moistened at intervals, but in spite of this the process of milling is never entirely free from the risk of accident, and special precautions are therefore taken to minimise the effect of an explosion.

The "cake" from the mills is now crumbled up into "meal" or dust, and becomes "gunpowder." In the early days this was no doubt the only form in which gunpowder was used, but nowadays it is only in the manufacture of fireworks that "mealed powder" is employed to any extent.[1]

It was not long before it was discovered that in

[1] Thus, although it is not unlawful for the occupier of registered premises to keep mealed powder for sale, the natural inference is that the purchaser requires it for the manufacture of fireworks. This is illegal except in a licensed factory, and on an inspector pointing this out a dealer will. as a rule, cease to stock powder in this form.

order to obtain the best results it was necessary to make up the powder into the grains with which most people are familiar, and for this purpose the meal is pressed by hydraulic pressure between plates of copper or ebonite, until a suitable density is obtained. The hard slabs from the press are then broken up by passing them through a succession of pairs of gun-metal rollers of gradually diminishing clearance, and the grains sorted into the different sizes by sieves of varying mesh.

The granulated powder is now "glazed" by being revolved for some hours in a large drum, either alone or with a small quantity of graphite. Thence it goes to the "stoves" or heated drying-rooms, and is finally "finished" in revolving reels of canvas to get rid of the dust and give the "colour."

How issued.—Blasting powder is now, as a rule, issued from the factory in the form of pellets or "bobbins." These are formed by hydraulic pressure and packed in boxes holding 25 or 50 lbs.—the pellets being wrapped up in pairs in paper wrappers. Blasting powder in grain is usually packed in 25 lb., 50 lb., and 100 lb. barrels, and sporting powder is generally issued in ½ lb., 1 lb., and 5 lb. tins.

Present Position.—Up to the year 1845 gunpowder was for all practical purposes the only explosive known. Moreover, for several hundred years there had been no material alteration either in its chemical composition or physical form. It was not until after gun-cotton had been invented, tried, and, as a propellant, proved a failure, that the effect of variations in the size and shape of the grains was fully realised. Roughly speaking, the larger the grain the slower the rate of burning, the result being that by using grains or rather cubes of 1½″ side, it was possible to fire without undue pressure the huge charges employed in the 80-ton gun and upwards. In the 110-ton breechloader, for instance, 960 lbs. (nearly half a ton) of gunpowder was used to propel a shell weighing 1800 lbs. (over three-quarters of a ton)—more than the whole of one of Nelson's broadsides!

Although gunpowder has for some time been superseded on the field of battle by cordite as a propellant, by lyddite as a burster for shells, and by gun-cotton for merely destructive purposes, at the covert-side by the countless nitro-powders, in the quarry by the gelatine dynamites, and in the coal-mine by the "permitted" explosives, it would still be difficult to name any one explosive better adapted for universal application to all purposes, and in view of recent improvements in manufacture it would be rash to prophesy that its days are numbered.

Risks.—In spite, however, of the intimacy that has existed for so many generations between this ancient explosive and the industrial population of these islands, there are unfortunately every year, in connection with its keeping and use, some hundreds of accidents causing death or bodily injury, and it is not too much to say that 99 out of every 100 of these might have been avoided by the exercise of reasonable care and common sense. The temperature required to ignite it is undoubtedly high in comparison with that required in the case of dynamite or gun-cotton, being about 540° F. against 360° F., and for this and other reasons it will most fortunately put up with a certain degree of ill-treatment without retaliating; but, on the other hand, this temperature, though relatively high, is actually very low when compared with the igniting points of many inflammable materials in common use, such as coal-gas, for instance; and when it is considered that even in powder factories, where every conceivable precaution is taken, serious accidents are not entirely preventible, and are sometimes due to the most trivial causes, it is surprising that the death-roll is not even greater. This applies both to the use and to the keeping of gunpowder, although the two conditions are materially different. The use is practically uncontrolled by legislation, but, on the other hand, the quantities involved are as a rule small, and the accident generally occurs in a quarry, mine, railway cutting, or some such place where no particular damage is done to surrounding material, and where therefore the apparent effect of the explosive is minimised. In stores, on the other hand, and on registered premises which are subject to legal supervision, the quantities of explosive involved in an accident are usually considerable, and the fact that the building in which the explosion occurs is generally completely wrecked tends, if anything, to exaggerate the power of the explosive and to produce a feeling of insecurity and panic, which has been known to culminate in a somewhat unpleasant demonstration against the local inspector. At Kilmarnock, for instance, in 1898 an explosion in an ironmonger's shop, by which a boy was killed and nearly a dozen passers-by injured, gave rise to a good deal of recrimination when it transpired that little or no attempt had been made by the local authorities either to register or inspect the premises. Not more than 30 lbs. or so of gunpowder had exploded, but the débris was scattered all over the market-place, and the damage was by no means confined to the premises on which the gunpowder was kept.

Since the date of the accident nothing could be more satisfactory than the manner in which the explosives trade is supervised in the above-mentioned burgh, but in view of the fortunate infrequency of serious accidents of the kind, and of the consequent improbability of a second occurring in the same place, this procrastinated zeal savours somewhat of shutting the stable door after the steed has been stolen. But the above is by no means an isolated case. In almost every instance in which an explosion on registered premises has drawn attention to any particular town, it has been found that the local supervision provided for by the Explosives Act has been lamentably neglected—a proof, if proof were needed, that the precautions enjoined by law are not unnecessary. These are fully discussed in Chapter IX.

CHAPTER III

Class II.—Nitrate Mixture

Definition.—*The term "nitrate mixture" means any preparation, other than gunpowder ordinarily so called, formed by the mechanical mixture of a nitrate with any form of carbon or with any carbonaceous substance not possessed of explosive properties, whether sulphur be or be not added to such preparation, and whether such preparation be or be not mechanically mixed with any other non-explosive substance.*

Put shortly, a "nitrate mixture" is a mechanical mixture (as opposed to a chemical compound) of a nitrate with any non-explosive substances, of which at least one contains carbon—gunpowder, of course, being excepted.

Why Gunpowder is excluded.—The necessity for this special exclusion of gunpowder by name is a result of that important provision of the Order in Council which directs that when an explosive falls within the description of more than one class it shall be deemed to belong exclusively to the latest of the classes within the description of which it falls. Thus if gunpowder were not specially excluded from Class II., it would undoubtedly belong to this class as being within the description of a nitrate mixture.

Necessity for granting Gunpowder special Privileges.—At first sight it may not appear to be a matter of much importance whether gunpowder belongs to the first or to the second class, but there is more in this matter than meets the eye. At the time the Explosives Bill was under discussion there were already in existence several Acts of Parliament dealing with explosives. Into the merits and defects of these it is not necessary to enter, but that there were deficiencies of such a nature as to justify fresh legislation may be taken for granted. The trade in gunpowder "ordinarily so called" was then solely governed by the Gunpowder Act, 1860, and not only was that Act remarkably innocent of any undue regard for the safety of the public, but such simple precautions as were enjoined could not be effectively enforced on account of the very limited powers of inspection. This comparative immunity from restriction was presumably deemed to constitute a kind of vested interest, which was acknowledged in the present Act by dealing with gunpowder separately from all other explosives. Consequently, although from the point of view of safety there may be no material difference between this explosive and other nitrate mixtures, it must for the sake of convenience be placed in a class by itself.

When is Gunpowder not Gunpowder?—But although gunpowder is thus by the force of circumstances in some degree relieved from legislative restrictions, it must not be assumed that this relief is in all cases entirely commendable, and it is therefore desirable that those responsible for the administration of the law should clearly understand when gunpowder ceases, so to speak, to be "gunpowder" and becomes another explosive, and consequently subject to the full restrictions applying to other explosives. This is a matter which has, on several occasions, given rise to discussion, and which, in so far as the question is relevant to a chapter on "nitrate mixtures," will now be briefly considered.

Gunpowder may, by a slight and apparently immaterial alteration, become—

(1) A nitrate mixture, Class II.
(2) Ammunition, Class VI.
(3) A firework, Class VII.; but only the first of these will be dealt with in this chapter.

The addition of any ingredient whatsoever to the mixture of saltpetre, sulphur, and charcoal forming "gunpowder ordinarily so called" converts it into a nitrate mixture of Class II. It is indeed more than probable that the mere substitution of nitrate of soda (Chili saltpetre) for nitrate of potash would contravene the definition, although this point is not likely to be raised, inasmuch as Chili saltpetre, owing to its affinity for moisture, is not well suited to the manufacture of gunpowder in this climate. Explosives such as aphosite, bobbinite, or oxalate blasting powder, which are chiefly composed of saltpetre, sulphur, and charcoal, and which are similar in appearance to pellet gunpowder, but which contain one or more additional ingredients are, however, undoubtedly nitrate mixtures belonging to Class II., with the result that—

A. They may not be kept in old gunpowder stores under continuing certificate.

B. As compared with gunpowder, only half as much may be kept in a store under license.

C. The quantity that may be kept on registered premises, may not exceed 60 lbs. in Mode A, or 15 lbs. in Mode B.

D. They may not be kept in a store, on registered premises, or for private use, without a police certificate of the form specified in Orders in Council 6[a], 16, and 12, respectively.

Types of Nitrate Mixtures.—The nitrate-mixture class is not an important one, and contains but few well-known explosives. It may roughly be divided into two general types:—

(1) Explosives such as those referred to above which only differ slightly from gunpowder.

(2) A few explosives of which the oxygen-carrier is

ammonium nitrate, and of which the combustible does not happen to be a nitro-compound. Of these the best known are electronite and westfalite.

Methods of Manufacture.—The manufacture of the first type is carried out in the same way as that of gunpowder. The ingredients are weighed, mixed, milled, pressed, granulated, and dried by the same processes, but the operation of glazing is generally omitted. The grains are finally either compressed into pellets, or put up loose into cartridges, and packed in boxes of 50 lbs. each.

The manufacture of the ammonium-nitrate type of explosive is a very simple process,—this is indeed by no means the least of its good points. Most of these explosives belong to Class III. merely from the fact that the most suitable combustible is, as a rule, a nitro-compound, such as di-nitro-benzol, nitro-naphthalene, or tri-nitro-toluol, but this does not affect the manufacture, which, with slight variations, is carried out as follows :—

The ammonium nitrate, which forms a large proportion of the finished explosive, after being sifted and dried, is thoroughly mixed with the other ingredients in a "pug mill," the bed of which is kept warm by a hot-water jacket. This is the whole process; but it must be properly done, otherwise the explosive will not always explode. After milling, the mixture, usually in the form of fine powder, is made up into cartridges either by hand or machine, and finally waterproofed by being dipped into a bath of melted paraffin wax or other similar substance. The material now most commonly used for the cartridge cases is an alloy of lead and tin, which only requires waterproofing at the end where the lid is screwed on after the case is filled.

Points of an Ammonium-Nitrate Explosive.—The good points of the ammonium-nitrate group of explosives are :—

(1) Simplicity and safety in manufacture.

(2) So far as past experience goes, they seem to be considerably less dangerous to handle and store than most other explosives.

(3) They do not freeze.

(4) They are not, as a rule, easily ignited by the direct application of fire, and when ignited there is no record of an explosion having resulted, unless a detonator is present.

(5) If they are kept too long or the cartridges subjected to rough handling, the affinity of the nitrate for moisture soon renders the explosive harmless. Moreover, there is practically no danger in throwing these explosives away, provided the cartridge cases are opened and the weather is not too dry.

(6) They are, as a class, relatively safe to use in "fiery" mines.

The bad points are :—

(1) To get the best results they require a large detonator,—itself a source of danger.

(2) Slight defects of manufacture or the access of a very little moisture may cause misfires or only partial detonation, or may even render the explosive entirely useless.

(3) The cartridges do not adapt themselves well to the shape of an irregular bore-hole.

On the whole, then, so far as regards keeping this type of explosive in stores and on registered premises, and the conveyance of it from place to place, it may fairly be claimed that it offers a higher degree of safety than any other nature of explosive of Classes I. to V. For its effective *use*, however, a detonator is indispensable, which reduces its standard of safety to that of the contents of the detonator, and this applies equally to cases of storage and conveyance where care is not taken to keep the explosive at a safe distance from detonators.

CHAPTER IV

Class III.—Nitro-Compound

Definition.—*The term "nitro-compound" means any chemical compound possessed of explosive properties, or capable of combining with metals to form an explosive compound, which is produced by the chemical action of nitric acid (whether mixed or not with sulphuric acid) or of a nitrate mixed with sulphuric acid upon any carbonaceous substance, whether such compound is mechanically mixed with other substances or not.*

More simply, a "nitro-compound" is an explosive formed by the action of concentrated nitric acid on any organic material, such as cotton, wood-fibre, glycerine, benzine, paper, etc. Sulphuric acid, although its presence is indispensable, takes no part in the process, its function being merely to absorb the water formed during the reaction, and thus keep the nitric acid at full strength. The nitro-compound class is divided into two divisions, the first of which comprises those explosives only which contain nitro-glycerine or other *liquid* nitro-compound, and the second all other nitro-compounds.

First Division.—The first division only will be dealt with in this chapter, and since there is at present no authorised explosive in this division which contains liquid nitro-compound other than nitro-glycerine, this division may be headed

Nitro-Glycerine Explosives

Nitro-Glycerine.—In the year 1847, that is to say, very shortly after the invention of gun-cotton, an Italian chemist made the discovery that by treating glycerine with a mixture of the strongest nitric and sulphuric acids an oily liquid was produced, heavier than the original glycerine and possessing powerful explosive properties. "Blasting oil" was the name given to it, but in this country it has generally been known as nitro-glycerine. For a short time it enjoyed a certain measure of popularity as a blasting explosive, on account of the ease with which bore-holes or even natural cracks and crannies could be charged with it. Unfortunately, however, it was not long before it gave rise to a series of accidents of so serious a nature that its use in the liquid state was prohibited in most civilised countries. Its very stability adds to its danger; for years it has been known to lie hidden and unchanged in some remote crevice in the rock or in the bend of an iron pipe, to blow to pieces some unsuspecting navvy or labourer engaged in his legitimate occupation with pick or hammer.

Dynamite.—Necessity, however, was in this case undoubtedly the mother of invention, and an explosive possessing the possibilities of nitro-glycerine was not to be rendered useless for want of a little ingenuity. After trial of many different substances, Alfred Nobel found that a siliceous earth called "Kieselguhr" could absorb and hold over three times its own weight of nitro-glycerine, and thus convert the liquid into a solid while sacrificing only a small proportion of its effective strength. To this red, greasy, earthy material he gave the name of "dynamite," meaning "strength" or "power."

Blasting Gelatine.—In so far, however, as this kieselguhr is an inert substance possessed of no explosive properties whatever, the complete explosive is inevitably less powerful than the original nitro-glycerine, and several attempts were consequently made by the same inventor with varying success to substitute a material capable of yielding at any rate a feeble explosion.

But in the year 1875 he made the discovery that certain varieties of gun-cotton, or rather nitro-cotton, could be partially dissolved in nitro-glycerine to form a gelatinous substance which he called "blasting gelatine." Not only did he thus introduce a powerful explosive in the place of the inert kieselguhr, but by a combination of nitro-glycerine which contains more oxygen than is needful, with nitro-cotton which contains too little, he produced an explosive of higher efficiency than that of either of the two ingredients alone. Practical considerations do not, as a matter of fact, permit the employment of the exact proportions theoretically desirable, but this explosive is nevertheless the most powerful in common use, and but for its cost would probably be selected for all work such as shaft-sinking or tunnel-boring, where a mere shattering effect is of the first importance, and the stone or other material is not required to be won in large blocks.

Gelatine Dynamite.—As an explosive of general utility, however, "blasting gelatine" possesses several defects. The ingredients are costly, the manufacture up to Home Office requirements in regard to exudation is not easy, and the action is too violent for many kinds of work. The proportion of nitro-glycerine was therefore reduced from about 90 per cent to 70 per cent, with a corresponding reduction in the nitro-cotton, and the balance made up of cotton, charcoal, and woodmeal. To this diluted blasting gelatine the name of "gelatine dynamite" was given.

Gelignite.—Finally, the nitro-glycerine was still further reduced to 60 per cent and saltpetre added, the result being "gelatine dynamite No. 2," commonly called "gelignite," which is now by far the most commonly used of all nitro-glycerine blasting explosives.

Points of the Gelatine Explosives.—The fact that nearly two-thirds of the authorised explosives belonging to this division of the nitro-compound class are based on nitro-glycerine thickened by being combined with nitro-cotton, is an indication of the popularity of the gelatines.

Their advantages are :—

(1) If properly made they are unaffected by water.

(2) They are plastic and easily adapted to an irregular bore-hole.

(3) They can be effectively used with a bore-hole of small diameter.

But on the other hand—

(1) They are comparatively easy to ignite by friction or percussion.

(2) They possess the common defect of all explosives containing more than a very small proportion of nitro-glycerine, *i.e.* they freeze at a relatively high temperature, say 40° F., and when once frozen do not completely thaw until the temperature rises to about 50° F., and it is thus quite common to find these explosives in sheltered magazines quite hard as late as June. The effect of this is twofold. First, they are when in this condition more liable to be exploded by rough treatment, and, secondly, they are less easy to explode by means of a detonator, with the result that there is more likelihood of unexploded cartridges being left at the bottom of a bore-hole or in the débris from a shot, to be struck later on by a workman's pick. Moreover, they are unfortunately even more sensitive to friction when in a half-frozen state, the reason being, no doubt, that small portions of semi-liquid nitro-glycerine on the softened outside of a cartridge are liable to be crushed between two broken crystalline surfaces of the still-frozen core, or to be unduly heated by the breaking of the crystals. Every

effort should therefore be made to ensure the use of the proper warming-pans to soften these explosives thoroughly before use, but *on no account* should they be thawed except by means of the regular appliances. The accidents caused by neglecting this precaution have been very numerous and deadly, but are happily becoming less frequent as the danger is more fully appreciated and the warming-pan more generally supplied. So important is this point considered that some few years ago a circular was issued from the Home Office to Chief Constables suggesting that the omission to furnish proper thawing appliances might well be regarded as sufficient grounds for withholding the police certificate without which it is unlawful to keep blasting explosives other than gunpowder. But one or two typical instances of catastrophes which have actually occurred may perhaps appeal with greater effect than reams of abstract advice.

Accidents in Thawing.—On July 15, 1897, at Airdrie, the brother of a well-known member of the explosives trade, in spite of instructions he had received that a consignment of frozen gelatine-dynamite should be thawed by merely leaving the magazine door open, thought he would expedite matters by bringing the explosive to his house, a cartload at a time. Hot water not being there available, the fire being low, he placed about 15 lbs. of the frozen material in the oven, turning the cartridges over and over as they softened. Summoned into the yard to help with the horse and cart, he had only been absent a few minutes when an explosion occurred which blew his wife and sister to pieces and wrecked the house. His remorse may well be imagined, and he has never fully recovered from the shock; but it all came of *thinking* the oven plate could not be too hot. Why not take advantage of that most useful law of nature which provides that water at ordinary pressure cannot be at a higher temperature than 212° F.?

Another case occurred at Porthcawl on January 10, 1898, in connection with a cutting for some sewerage works. During the breakfast interval the chargeman proceeded to thaw about 2 lbs. of frozen gelignite in a flat pan on a brazier in which the fire was burning low. After a few cartridges had been successfully treated, the remainder exploded, killing the chargeman and a mate, and severely injuring two others.

Many more similar instances might be given, and in almost every case it would be found that the responsible person was possessed of just that little knowledge which is well said to be such a dangerous thing. He would probably deem it as much as his life was worth to apply a lighted match to a cartridge of gelatine-dynamite, whereas—even though such an act would be inexcusably senseless—the direct application of a flame to a single cartridge would quite possibly merely cause it to burn away inexplosively. A nitro-compound, in fact, is in this respect quite different from gunpowder.

Risks compared with Gunpowder.—Heat up a single grain of a mass of gunpowder to the ignition temperature of sulphur, and the whole will explode, but until that temperature is reached there is practically no danger, except that as the temperature rises so much the less additional heat is required to cause ignition, and the powder therefore becomes more sensitive to shock. But in the case of a nitro-compound it is by no means necessary that the temperature should reach the igniting point for an explosion to take place. Even when thoroughly well made an explosive of this class cannot be exposed for any length of time to an elevated temperature, even though far below its igniting point, without decomposition setting in. This chemical action develops more heat, which in its turn increases the chemical action, and so on, and thus sufficient heat is produced to cause explosion. This is of course the true explanation of the process known as spontaneous combustion, and may result either from the chemical action set up by heat or from the heat produced by chemical action due to the presence of acid or other impurity. Moreover, the heat may be applied, or the chemical action started, either locally or generally, with but little difference in the result, except that in the latter case explosion would, *cæteris paribus*, occur sooner. The explosion at Aden of two magazines containing blasting gelatine in May and June 1888, which were undoubtedly due to spontaneous ignition, proves beyond question that even the ordinary temperature of the tropics is in certain circumstances sufficient after a time to decompose a nitro-compound containing a slight trace of impurity.

Other Nitro-Glycerine Explosives.—The whole of the above applies with equal force to the ungelatinised nitro-glycerine explosives which practically form the balance of this division of the nitro-compound class. The best known of this group are dynamite and carbonite. Reference has already been made to dynamite as being the first adaptation of nitro-glycerine to practical purposes, and its appearance has also been described. Carbonite contains about a quarter of its weight only of nitro-glycerine, the remainder being chiefly woodmeal and saltpetre, and the original explosive of this name presents the appearance of a friable, brown, tobacco-like material. In consequence, however, of the actual composition of an authorised explosive being now regarded by the Home Office as confidential (unless circumstances should arise to render it advisable to publish it), several compounds have been authorised of practically the same composition as carbonite, some of which, by a slight change in the nature of the woodmeal, have been given an entirely different appearance, and it is not easy, therefore, to give a description which will include all; but it may be generally assumed without much fear of error that a blasting explosive which is neither gunpowder, nor red dynamite, nor gelatinous, nor in the form of a fine yellow or buff powder in a waterproofed cartridge, is of the nature of carbonite.

Their special Risks.—This group of nitro-glycerine explosives, in which the ungelatinised liquid is held merely by the absorbent qualities of the other constituents, possesses the serious defect that in contact with moisture the nitro-glycerine invariably exudes owing to its easy displacement by water. This exudation is in all cases undesirable and dangerous, and, if occurring under ordinary conditions of storage, renders any nitro-compound in this division liable to forfeiture; but kieselguhr dynamite is pre-eminently the explosive presenting the greatest weakness in this direction, and stores in which it is proposed to keep this material should therefore, of course, be reasonably free from damp, or steps should be taken to prevent the moisture accumulating and dripping on to the dynamite. But it is not during storage that the chief danger arises, since a magazine or store so wet as to lead to actual contact between the explosive and the deposited moisture would for other reasons be highly unsuitable for its purpose. The majority of recorded accidents from this cause have occurred when dynamite, either during conveyance or when in use, has been actually immersed in water; in these circumstances nitro-glycerine exudes at once, and water takes its place with little or no change in the appearance of the dynamite, and with no indication whatever that a considerable quantity, it may be, of the deadly liquid is lying at the bottom of the vessel containing the water. Thus at Craig, near Montrose, in March 1880, a party of quarrymen, having thawed some dynamite by placing the tin containing it in a kettle of hot water, failed to notice that a leak in the tin had allowed the hot water to displace a portion of the nitro-glycerine, and that this nitro-glycerine had consequently escaped into the kettle, and, being heavier than water, had sunk to the bottom. Shortly afterwards, requiring some hot water for cooking, they placed the kettle on the fire and sat round it as usual. Presently an explosion took place which killed five of them and injured another. Again, in the year 1885, two men were killed at Larne when engaged in breaking up an old cast-iron pump shaft from a hulk which had once been used as a magazine, but in which no dynamite had been kept for nine years. On one of the men dealing the iron pipe a blow with a heavy hammer a violent explosion took place, killing both and doing a considerable amount of damage. The evidence taken at the inquiry showed that the dynamite formerly kept in the vessel had, owing to her leaky state, frequently been under water, and that a quantity of nitro-glycerine had undoubtedly exuded and lodged in the pump shaft, to deal out death and destruction nine years later!

Cordite.—Cordite and ballistite may be dismissed in a few words. The former, consisting, as its name implies, of cords of varying diameter, is seldom or never met with except in factories and in Government magazines, and the latter is only found in stores and on registered premises in the form of the small flakes used for sporting purposes. Even in this form, however, its presence is rare, inasmuch as cartridges containing it are generally loaded at the factory. The principle of these two explosives is practically the same—a proportion of nitro-cotton varying between thirty-seven and sixty-five per cent by weight of the finished product, is combined with nitro-glycerine, and by treatment with a suitable solvent is converted into a horny material so impervious to hot gases that each cord or flake can only burn from outside to inside in the same manner as a grain of gunpowder, and the rate of combustion can thus be regulated as required by varying the size of the cords or flakes. Thus the cordite for use in revolvers is only one hundredth of an inch in diameter, and has the appearance of coarse hair, whereas for heavy cannon each cord may be more than half an inch thick.

Briefly, then, the nitro-glycerine blasting explosives may for all practical purposes be divided into three types, viz.—

Dynamite,
The Gelatines,
Carbonite,

and there should not now be much difficulty in recognising to which of these types any particular sample belongs. There are a few others, such as stonite, Ardeer powder, etc., but they are seldom met with.

Method of Packing Nitro-Glycerine Explosives.—A blasting explosive containing nitro-glycerine may not lawfully be packed for conveyance in a box or case any part of which is made of metal, and the same rule should be observed in connection with the receptacle in which it is kept on registered premises. The reason of this is that in case of exudation the chance of accident from a blow would be vastly increased by the presence of the explosive liquid on a metallic surface. Exudation is now happily limited, as a rule, to a slight trace of moisture on the paper wrappers of the cartridges; but not so very long ago it was by no means uncommon to find a considerable deposit of nitro-glycerine in a case of explosive, and although it is not probable that a manufacturer of standing in this country or on the Continent would knowingly allow such dangerous rubbish to leave his factory, what has happened once may happen again. In the United States, where the explosives industry is practically uncontrolled by legislation, cases of serious exudation are of alarming frequency, and have sometimes led to disastrous accidents.

Process of Manufacture.—A short description will now be given of the usual method of making nitroglycerine, and of converting it into the various explosives based on it.

A mixture is first made of the strongest nitric and sulphuric acids in the proportion of about eight parts by weight of sulphuric to five parts of nitric. This mixture when cool is run into the nitrating vessel, and glycerine to an amount equal to about one-eighth the weight of the mixed acids is gradually injected by means of a spray. The action of the nitric acid on the glycerine causes a rise of temperature, and it is most important that this should be checked as far as may be, and that there should be a simple method of safely getting rid of the charge in the event of a dangerous and uncontrollable development of heat. For this purpose the interior of the vessel is surrounded with a coil of piping in which cold water is kept continually running, and the mixture is stirred during the whole process of nitration by means of compressed air in order to dissipate any local heating that may result from the presence of a drop of water or other slight impurity which may possibly have found its way into the vessel in spite of all precaution. Meanwhile, a large, clearly-marked thermometer standing in the mixture is unceasingly watched by a trustworthy man, whose orders are that if, in spite of all cooling arrangements, the mercury rises to a certain height, he is to "drown" the charge and leave the building. The operation of drowning merely consists in turning a tap connecting the bottom of the nitrating vessel, by means of a pipe of large diameter, with a tank of water situated under or near the building, into which the nitro-glycerine and acids can be run in a few minutes, and from which the former may be subsequently recovered.

Under normal conditions, however, a fall in temperature occurs as soon as the whole charge of glycerine has been converted into nitro-glycerine, and the contents of the vessel are then run by gravity into a tank on a lower level called the "separator" and allowed to settle. The explosive, being lighter than the mixed acids, soon forms on the top, and is then transferred to the washing tanks, where it is repeatedly agitated with water and soda until all trace of acid has disappeared. Finally, it is filtered through flannel, on which there is generally, but not always, a layer of common salt to absorb the small particles of water entangled in the nitro-glycerine. The theoretical yield from 100 parts of glycerine is nearly 247 parts of nitro-glycerine, but in practice 210 to 215 parts is considered a good result.

Conversion into Solid Explosives.—The explosive is now ready for use; but as its manufacture is only licensed "for immediate conversion into an explosive authorised to be manufactured in the factory," it is now weighed out into india-rubber jugs and poured on to the kieselguhr, gun-cotton, or other solid absorbent, after which its further history is merged in that of the explosive of which it forms such an essential part, and a very brief outline of the usual method of preparing the three typical nitro-glycerine explosives, *dynamite*, *cordite*, and *gelignite*, will conclude the chapter.

Dynamite.—For *dynamite* the proper proportion of nitro-glycerine is poured on to the kieselguhr in a brass or rubber-lined box, roughly stirred up, and transferred to the mixing-house, where the crude mixture is thoroughly incorporated by hand until it assumes the appearance and consistency of moist red-brown earth, and becomes finished *dynamite*; this then goes to the cartridge huts, and by means of a plunger worked through a hopper by a pump handle is converted into blasting cartridges,—practically the only form in which it is now met with.

Cordite.—*Cordite*, including the kindred explosive, *Cordite M.D.*, calls for more elaborate treatment, and for far greater accuracy in manufacture, inasmuch as on its uniform behaviour depends the efficiency of the gun in which it is fired, and a variation which would be quite immaterial in a blasting explosive might in a propellant make all the difference between a hit or a miss. Thus the nitro-glycerine, if intended for cordite, is subjected to more severe tests than would otherwise be deemed requisite, and the utmost care is taken at each stage of manufacture to ensure perfect uniformity both in chemical composition and in physical form. The process is very briefly as follows :—

The nitro-glycerine having been poured on to the gun-cotton in proper proportion, the rough mixture is taken to the hand-mixing house, in which it is rubbed through a sieve and becomes "cordite paste"; this paste is then kneaded for about seven hours with a due proportion of acetone and vaseline in a machine originally designed for kneading bakers' dough, the acetone, which is a solvent both of nitro-glycerine and gun-cotton, causing the mass to assume the consistency of this material. The "cordite dough," as it is now called, is then "squirted" by hydraulic pressure through dies of suitable diameter in the same way as lead pipes are made, cut into the prescribed lengths, and taken to the drying chambers, where the evaporation of the solvent causes the now finished cordite to lose its plasticity, and converts it into the semi-horny cords from which its name is derived. The size used for rifle cartridges, being only ·0375 of an inch in diameter, is, however, wound on reels on leaving the dies, and is not cut into lengths until actually required in the cartridge-loading room.

Gelignite.—*Gelignite* is made in a somewhat similar manner, but the nitro-cotton used is of a kind that is soluble in nitro-glycerine, so that no other solvent is required, the operation of "drying" being thus dispensed with and the plasticity retained. The ingredients are thoroughly incorporated in a hot-water jacketed machine, and the resulting dough is then transferred to the cartridge huts, where, by means of a hopper and screw worked by hand, it is pushed through a tube like a long sausage, and cut into suitable lengths for blasting cartridges.

CHAPTER V

Class III.—Nitro-Compound—*continued*

Definition of Second Division.—The second division of this class consists of those nitro-compounds which do not belong to the first division—that is to say, which do not contain nitro-glycerine or other liquid nitro-compound.

Nitro-Cellulose.—The majority of the explosives in this division are based on nitro-cellulose—that is, on cellulose, such as cotton, wood-fibre, or paper, which has been treated with nitric and sulphuric acids in a somewhat similar manner to that described in the last chapter in connection with the manufacture of nitro-glycerine.

Ammonium Nitrates.—About a dozen or so of the explosives in this division belong, however, to the ammonium-nitrate group, and, as pointed out in Chapter III., are only technically classified as nitro-compounds in that they each contain a small proportion of a combustible nitro-compound such as di-nitro-benzol, tri-nitro-toluol, etc., and their manufacture does not materially differ in its methods from that already described in Chapter III. when dealing with such explosives of this group as are nitrate mixtures. The best known are ammonite, amvis, bellite, Faversham powder, and roburite. With the exception of picric acid there is no other well-known explosive in this division which does not contain nitro-cellulose in the form either of gun-cotton, collodion cotton, or nitro-lignin.

Gun-Cotton.—It was in the year 1845 that Schönbein revolutionised the explosives industry by discovering a practical method of making gun-cotton by treating cotton with a mixture of concentrated nitric and sulphuric acids. It was at once assumed that this new and powerful explosive could, for all purposes, take the place of gunpowder, and more particularly that it could be used as the propelling charge in rifles and cannon. A succession of accidents soon showed, however, that, as with nitro-glycerine, it was in its crude state quite unsuitable not only for use but even for storage in large quantities; and although a serious attempt was made to introduce it into the Austrian service as a propellant in field guns, it was soon found that, in spite of various material improvements in the mode of preparing the cotton, the explosive was of so unreliable a character as to render it practically useless for this purpose,—as indeed in its untreated state it still remains; and moreover its chemical stability was still insufficient to enable it to be safely stored for any length of time, so that it gradually fell into disrepute.

Abel's Pulping Process.—But, just as Nobel rescued nitro-glycerine, so Abel saved gun-cotton by the discovery that perfect stability could be secured by perfect purity, and that, by reducing the nitro-cotton to a pulp, and by thoroughly and repeatedly washing this pulp until free from acid or other impurity, the explosive could be kept unchanged for many years, either in the dry or wet state.

Detonation Wet or Dry.—Later it was found that the explosion in contact with gun-cotton of a small quantity of a very violent explosive such as fulminate of mercury would cause compressed gun-cotton to "detonate" even when entirely unconfined, and that, moreover, wet gun-cotton could be detonated by means of a primer of the dry material, so that when compressed by hydraulic means it could, while still wet, be cut into any shape and carried in the same condition from place to place with perfect safety. It possesses the further advantages that it does not freeze in cold weather, nor does it ever exude a liquid explosive, and it was thus soon established as a most suitable explosive for purposes of hasty demolition in time of war—a position which it still holds.

Stowmarket Explosion.—It was at one time very generally believed, even by experts, that dry gun-cotton unless strongly confined would, if ignited, merely burn away without explosion, irrespective of the quantity involved,—and the same is said of certain other explosives in the present day; but the fallacy of this was unfortunately exposed in a very dramatic manner by the awful catastrophe at Stowmarket in 1871, when about 13 tons of gun-cotton, into which acid had been maliciously introduced, took fire spontaneously, and by its subsequent explosion killed no less than 24 persons and injured more than 50 others. The advantage, therefore, of being able to keep or carry it in so wet a condition as to be absolutely uninflammable, and yet, by means of a small dry primer weighing no more than a few ounces, to explode the whole mass without the necessity of drying it first, can hardly be overestimated. In spite of this, however, and of the fact that wet gun-cotton containing not less than 20 per cent of water is exempted from many of the restrictions imposed by the Explosives Act, it is but little used for industrial purposes, and consequently is not often met with in stores and registered premises.

Points of Gun-Cotton.—The cost is high, and when compressed into hard slabs or discs—the only condition in which it can be effectively used—it is not easily adapted to the shape of an irregular bore-hole. Moreover, as already stated, it does not contain within itself sufficient oxygen for complete combustion, so that it produces on explosion a considerable proportion of the deadly carbon monoxide gas (CO). To meet the two defects of high price and noxious fumes a comparatively cheap oxygen-carrier such as saltpetre or nitrate of barium was eventually added to the gun-cotton, and the resulting explosive, under the name of cotton powder or tonite, has since been extensively used for blasting purposes.

Collodion Cotton.—Without going into the somewhat vexed question of the exact chemical constitution of the gun-cotton molecule, it may not be amiss to point out that the stronger the acids used the higher will be the degree of nitration and consequent percentage of nitrogen in the finished product, and that when this percentage falls to 12·3 the material is known as collodion cotton, and when wet is not then regarded as an explosive. In the dry state, however, serious explosions of collodion cotton have been recorded, its difference from gun-cotton being merely one of degree, and even the very moderately nitrated material used in the manufacture of celluloid, and which as a rule contains less than 11 per cent of nitrogen, has recently given evidences of considerable explosive power.

Process of Manufacture of Nitro-Cotton.—The method of manufacture is essentially the same whatever the degree of nitration. Into a tank of the mixed acids about 1 lb. at a time of thoroughly clean, well-carded, and dry cotton is quickly plunged by means of a rake. After a short immersion the cotton is removed and allowed to drain into the tank, after which it is placed in a covered pot to digest, the pots standing during this process in a shallow tank of cold water. As soon as the whole of the cotton has been converted into nitro-cotton, the contents of half-a-dozen pots are placed in a centrifugal wringing-machine provided with a perforated iron cage which can be revolved at great speed, and by means of which the superfluous acid is whirled out of the charge in a few minutes. During this operation it is by no means uncommon for a charge to "fume off," as it is called, *i.e.* to be spontaneously decomposed and converted into gases and fumes similar to those produced on combustion. A drop of rain, or even of sweat off a workman's face, has been known to give rise to this occurrence, but it is seldom that personal injury results. The gun-cotton is now removed and immersed in a large tank of water, and repeatedly washed by running off the water and refilling with fresh until the cotton is found to be free from acid taste, when a little soda is added for a final wash. After being again wrung out in a centrifugal, the explosive is next cut up and beaten by a suitable machine until it is in the form of fine pulp, when it is run by gravity into large wooden vats and boiled by steam for a whole day. Finally it is stirred up in a "poacher" fitted with revolving paddle-wheels, and samples taken for testing.

If the tests are satisfactory, lime-water and other alkaline substances are added, and the pulp drawn off to the supply tanks of the moulding machines, in which, by a light pressure of 30 lbs. or so per sq. inch, the pulp is reduced to a form and consistency in which it can be carefully handled. The moulded gun-cotton is now, if required for military purposes, transferred to the press and subjected to hydraulic pressure amounting to about 6 tons on the sq. inch, the resulting slabs or discs being sawn while still wet into any required form.

Such is very briefly the method of manufacture usually employed, with slight variations, according to the purpose for which the explosive is to be used; and it is obvious that since the chief operations are carried out under water the danger is reduced to a minimum.

Usually Packed Wet.—For conveyance or storage it is packed as a rule in water-tight cases, and contains about 20 per cent of water, which is sufficient to render it quite uninflammable; even when exposed to the action of fire it will only smoulder away. When dry, however, it is very sensitive to percussion and friction, especially when warm; but if ignited in small quantities by the direct application of a flame, it will, if unconfined, burn away without explosion.

Smokeless Sporting Powders.—As already stated, nitro-cotton, pure and simple, is not well adapted for general use in mines and quarries; but, on the other hand, after suitable treatment, it forms the basis of nearly all the numerous smokeless sporting powders now in the market. Reference has been made to the failure of all attempts to render it available as a propellant, even the most rigid compression not having been successful in preventing the instantaneous penetration of the hot gases throughout the mass of porous cotton, with the result that the rate of combustion could not be controlled, and the initial pressure in the bore of the gun was consequently far too high for practical purposes. Eventually, however, it was found that by treating nitro-cotton with a suitable solvent, which could be subsequently removed by evaporation, a hard, horny, non-porous material was obtained, quite impervious to the hot gases, and which would therefore burn regularly from the outside of each grain, or cube, in the same way as gunpowder. This discovery, first practically utilised by Schultze, led to the production of a vast number of sporting powders differing slightly in regard to colouring matters and other unimportant constituents, but in almost every case consisting of nitro-cellulose alone, or with the addition of nitrate of barium, potassium, or sodium, and gelatinised wholly or partly by means of a suitable solvent such as alcohol, acetone, ether, nitro-benzol, or a mixture of these. The presence of a metallic nitrate, of course, prevents a powder from being entirely smokeless, as a certain quantity of solid residue must be formed; but it is an ingredient of many of the best known and most popular powders, so that the advantages presumably outweigh the disadvantages.

Requirements of a good Sporting Powder.—The requirements of a good sporting powder are—

(1) It should be stable and should keep well under ordinary conditions. This depends largely on the purity of the ingredients and particularly on that of the nitro-cellulose.

(2) It should be regular in its shooting, *i.e.* the pressure, muzzle velocity, and "pattern" should not vary beyond certain limits.

(3) The smoke and unconsumed residue should not be noticeable.

(4) The recoil and report should be reduced to a minimum. During one of the big covert shoots of the present day, or in a day's grouse or partridge driving, the cartridges fired by each gun of a party will probably amount to many hundreds, and the quality of the blow dealt by each on the shoulder and the ear-drum may make all the difference between enjoyment and the reverse.

(5) It should be well adapted to the cap with which it is intended to be used, otherwise slight hang-fires may result, and nothing is more irritating to a shooter.

(6) It should not call for any special skill on the part of the cartridge loader.

Method of Manufacture.—The method of manufacture is practically the same for all the best known powders, and is briefly as follows :—

The thoroughly purified nitro-cellulose while still wet is mixed or impregnated with the nitrate or other ingredient, and granulated by being rubbed through a sieve. The soft damp grains are then dried by hot air at about 100° F. and removed to the solvent house. Here they are slowly revolved in a drum of peculiar construction, the solvent being meanwhile sprayed over them so as partially to dissolve each grain, and give it, after the solvent has evaporated, the requisite hard and horny consistency. Each factory has its own machinery and minor variations, and the powder is after hardening finally dusted and blended before packing; but the manufacture is in one sense of so simple a character as to give little opportunity for wide differences in method, and the above brief description applies fairly well to the great majority of sporting powders. This is by no means intended to imply that little skill is required in the production of a good smokeless powder, as quite the contrary is the case; but the actual operations of manufacture are in their main characteristics identical for all, and it is only in the numberless apparently insignificant details that the expert has a free hand.

Picric Acid and its Salts.—Picric acid and its derivatives, picric powder and picrate of ammonium, form the last group of this division to be dealt with, and of these, picric acid is the only one deserving more than a passing notice. Picric powder is a mixture of picrate of ammonium and saltpetre, and is only used in shells as a primer to explode picric acid. It is of a light yellow colour and requires strong confinement to develop its explosive properties. Picrate of ammonium is but feebly explosive, and used only in the manufacture of picric powder.

Picric acid, however, is an explosive of considerable importance, inasmuch as under various names, such as lyddite, melinite, etc., it is now widely used as the bursting charge of shells. For many years this material had been employed as a yellow dye before any attempt was made to make use of the explosive powers which from its chemical formula it undoubtedly possessed; indeed, until quite recently the state of the law in regard to it was most unsatisfactory, and it was by no means easy for the local authorities and railway and steamship companies to determine whether it should be treated as an explosive or as a harmless chemical. This anomalous state of affairs has now, however, been rectified by the recent Order in Council on the subject, by which a substantial quantity, amply sufficient to meet the usual requirements of the dyeing trade, may, under certain conditions, be kept and conveyed as if it were not an explosive, while, on the other hand, larger quantities will always be treated in the same way as any other explosive nitro-compound, for whatever purpose it may be intended. The above refers to the dry crystals, but the same exemption applies to any quantity of picric acid when mixed with half its weight of water, so that it may fairly be claimed that every facility compatible with public safety has now been granted to the trade, while at the same time the question as to whether a given consignment is to be dealt with as an explosive or not can be at once settled merely by weighing it or inspecting it.

Properties and Risks.—Picric acid is a bright yellow crystalline substance, with an extremely bitter taste, and is only slightly soluble in water. It melts at a lower temperature than its ignition-point, and in its fused state is called "lyddite" and used as a burster for shells.

Lyddite.—It can be detonated by fulminate of mercury or by a picrate. In moderate quantities it will if unconfined burn away without explosion, but if during a conflagration it comes in contact with a base with which it can form a picrate, more especially picrate of lead, the explosion of this will detonate the whole mass of acid, even if wet. Indeed it has never been clearly proved that even large quantities of picric acid will, if burnt alone and unconfined, give rise to an explosion, inasmuch as there are as a rule so many opportunities in the course of a big fire for the formation of these dangerous salts, that it is almost impossible to be quite sure that an explosion is not due to the presence of one or more of them. Be this as it may, however, all experience proves that, however great may be the quantity of picric acid present in a conflagration, little danger from explosion need be apprehended until the fire has been in progress for some time, assuming of course that the acid is not strongly confined; and no danger is therefore at all likely to accrue from the above-mentioned conditional exemption of moderate quantities from the provisions of the Explosives Act. Being deficient in oxygen, picric acid when completely detonated produces a black smoke due to the free carbon left unoxidised, but in actual practice there is generally a proportion of the unburned acid scattered about, and this bright yellow powder against the blue background of the sky, or when mingled with the pulverised stone and earth thrown up by a bursting shell, no doubt gave rise to the "green fumes" to which reference was so frequently made during the recent war in South Africa.

CHAPTER VI

Class IV.—Chlorate Mixture; and Class V.—Fulminate

Definition of Chlorate Mixture. — *The term "chlorate mixture" means any explosive containing a chlorate.*

The class is divided into two divisions, the first consisting of those chlorate preparations which contain nitro-glycerine or other liquid explosive, and the second of those which are not comprised in the first division.

Chlorate of Potash as Oxygen-Carrier.—Reference has already been made to the part played in an explosive by the oxidising agent, and it has been shown how, by reason of the great affinity that exists between oxygen and carbon, hydrogen and sulphur, the application of a moderate degree of heat is sufficient to induce saltpetre or *nitrate* of potash to transfer its oxygen to the above-mentioned substances with great evolution of heat and liberation of large quantities of inert nitrogen which may be said to take no interest in the proceedings. With *chlorate* of potash the same thing occurs, but with the very important difference that, not only does the oxygen, owing to its affinity for combustibles, readily enter into recombinations, but the chlorine, unlike the inert nitrogen in the nitrate, has strong affections of its own and does its utmost to assist the reaction.

Risks.—Moreover, owing to circumstances in connection with its formation, chlorate of potash develops considerable heat on decomposition, the result being that not only is an explosive containing chlorate more sensitive as a rule to percussion and friction than a compound in which the oxygen-carrier is a nitrate, but it is also more violent in its action, and for these reasons compositions containing these salts—more particularly chlorate of potash—have for many years exercised an extraordinary fascination on those engaged in explosive research. Many serious accidents have, however, occurred even during the simple laboratory operation of mixing chlorate of potash and sugar or other combustible with pestle and mortar; explosions have even taken place with chlorate of potash lozenges, and in fact as a carrier of loosely combined oxygen this substance may be regarded as only too efficient.

Defect of Chlorate Explosives.—But mere sensitiveness is no great defect since there are many methods by which this may be overcome, and if this were the only failing possessed by these explosives it is more than probable that a large number would have been authorised. Unfortunately, however, especially after exposure to wide differences of temperature in the presence of moisture, the chlorate is liable to crystallise out on the surface of the explosive—a condition which gives rise to a considerable *increase* of sensitiveness, to which there is practically no limit. A moment's reflection makes it clear that it is safer to deal with a highly sensitive explosive of which the degree of sensitiveness is known, than with another which, although originally vastly less sensitive, may in course of time develop dangers of the measure of which the user may be quite ignorant, and it is this increase of sensitiveness that renders it so difficult for an inventor to produce a chlorate explosive which will pass the Home Office tests and obtain a place on the list of "authorised" explosives.

Difficulty of obtaining Authorisation.—On reference to the Annual Reports issued by H.M. Inspectors of Explosives it will be found that several explosives of this class have been authorised from time to time, but that, for one reason or another—usually on account of the small proportion of chlorate—they have not given satisfaction, or at any rate have not been found suitable for general use, with the result that their manufacture or importation has died out and they are no longer licensed. Others have passed the tests, but have never been actually licensed, the consequence being that at the present moment the three varieties of cheddite are the only authorised explosives in the class. This explosive, however, fathered as it is by one of the best known firms in the trade, has passed the experimental stage and seems likely to remain.

Method of Manufacture.—The process of manufacture is extremely simple, and consists merely in thoroughly mixing the ingredients in a steam-jacketed bath, and inserting the mixture in paper cartridge wrappers, which are then waterproofed by being dipped in melted paraffin wax.

To obtain good results with cheddite, however, it is unfortunately necessary to fire it by means of a detonator, thereby adding largely to the risk in handling and use. But since a nitrate mixture, such as gunpowder, can be very effectively fired by fuze only, there would seem to be no reason why a chlorate mixture should not eventually be produced of such a nature as to be capable of yielding the best results on mere ignition, and it is possible that such an explosive would have a great future.

CLASS V.—FULMINATE

Definition of a Fulminate.—*The term "fulminate" means any chemical compound or mechanical mixture, whether included in the foregoing classes or not, which, from its great susceptibility to detonation, is suitable for employment in percussion-caps or any other appliances for developing detonation, or which, from its extreme sensibility to explosion, and from its great instability (that is to say, readiness to undergo decomposition from very slight exciting causes), is especially dangerous.*

This class consists of two divisions.

Division I

This division comprises such compounds as the fulminates of silver and of mercury, and preparations of these substances, such as are used in percussion-caps, and any preparation consisting of a mixture of a chlorate with phosphorus, or certain descriptions of phosphorous compounds, with or without the addition of carbonaceous matter, and any preparation consisting of a mixture of a chlorate with sulphur, or with a sulphuret, with or without carbonaceous matter

Division II

This division comprises such substances as the chloride and the iodide of nitrogen, fulminating gold and silver, diazo-benzol, and the nitrate of diazo-benzol.

Second Division.—The second division may be dismissed at once. It contains no authorised explosive, and those enumerated as types possess no practical value whatever and may be regarded more as chemical curiosities than as useful assistants in the Arts. All are dangerous, and some are so sensitive as to explode violently when tickled with a feather or exposed to a ray of sunlight, and even the honest inquirer into the secrets of nature would be well advised to carry out his inquiries in some other direction lest his discoveries make too great an impression on him to be pleasant.

First Division.—Before discussing the first division of this class it may be well to point out that although the class is referred to as the "fulminate" class, and fulminate of mercury, the sole authorised explosive, is the best known of the class, a compound may be legally a fulminate, even though it contains no fulminate in its composition. The purpose, in fact, for which it is suitable and its general characteristics determine its classification independently of the ingredients composing it. Many mixtures used in percussion-caps, for instance, are quite free from fulminate of mercury, yet they belong to the "fulminate" class of explosive.

Fulminate of Mercury.—Fulminate of mercury is, as above stated, the most commonly used of all fulminate explosives—chiefly in the manufacture of detonators. These sometimes contain nothing else, some of those employed to fire submarine mines being charged with over 70 grains of the pure fulminate, but as a rule a percentage of chlorate of potash is added to give coherence; further reference will, however, be made to this subject under the heading of "detonators."

Process of Manufacture.—The manufacture of fulminate of mercury is in the hands of two or three firms. Mercury is dissolved in nitric acid and the solution treated with alcohol. The fulminate is deposited in the form of a grey powder, which is washed until quite free from acid, and stored in bags under water. A redeeming feature of this otherwise highly sensitive explosive is its insolubility in water, so that it can not only be kept for an indefinite time under water, but may, if properly packed as provided by law, be conveyed without danger by land or sea. It must not be forgotten, however, that although the fulminate when wet is harmless alone, it can be detonated even in that condition by a primer of the dry explosive, and every care must therefore be taken to prevent small quantities finding their way out of the receptacle and becoming dry. When required for use it is laid out on cloths a few pounds at a time, and dried by artificial heat; it is then carefully weighed out in charges of a few ounces prior to being taken to the mixing shed to be mixed with the other ingredients—if any.

Although an authorised explosive, fulminate of mercury may not be kept in stores, on registered premises, or for private use under police certificate, so that it is practically authorised only for manufacture and importation, and not for general sale.

Fulminate of Silver.—Fulminate of silver is largely used in minute quantities in the manufacture of toy fireworks such as bonbon snaps, throwdowns, and crackshots. It is prepared as required, and the method is in principle the same as that already described, but the apparatus is of the most primitive order, consisting usually of an empty ginger-beer bottle. Since, however, the quantity which may be present on the same premises at any time may not exceed a weight which is measured in grains, a serious accident cannot well occur, and as a matter of fact no accident of any kind is recorded at the Home Office as having taken place in a toy-firework factory.

CHAPTER VII

CLASS VI.—AMMUNITION

Definition.—*The term "ammunition" means an explosive of any of the foregoing classes when enclosed in any case or contrivance, or otherwise adapted or prepared so as to form a cartridge or charge for small-arms, cannon, or any other weapon, or for blasting, or to form any safety or other fuze for blasting, or for shells, or to form any tube for firing explosives, or to form a percussion-cap, a detonator, a fog-signal, a shell, a torpedo, a war-rocket, or other contrivance other than a firework.*

The above is very clear and explains itself, the net result being that an explosive, unless it is actually issued in bulk, not even made up into cartridges, must be either ammunition (Class VI.) or firework (Class VII.). By a special provision of the Act, however, an explosive when made up into cartridges not containing their own means of ignition, *i.e.* when merely wrapped up in packages of convenient size and shape for use in cannon or for blasting, is to be regarded for purposes of storage as if it were not so made up, and is to be packed for conveyance in the same manner as it would be if in bulk, except that the cartridge wrapper may, if efficient, take the place of the inner package required by law.

First Division.—The ammunition class consists of three divisions. Of these the first may be termed the "safety" division, inasmuch as the indispensable condition to be fulfilled by every explosive included in it is that the explosion of one such explosive will not communicate to other similar explosives, and an explosion of any magnitude is thus rendered impossible. By Order in Council this division is limited to four explosives.

(1) **Safety Cartridges.**—These are defined in the Act as "cartridges for small-arms of which the case can be extracted from the small-arm after firing, and which are so closed as to prevent any explosion in one cartridge being communicated to other cartridges"; and experience has shown that this may safely be deemed to include all rifle, pistol, and sporting cartridges in common use. Even the large cartridges used in elephant guns have been shown by experiment to come within the definition, since the explosion of one was not found to communicate to another unless the cartridges were so arranged before firing that the bullets of some were actually in contact with the caps of others. This communication of explosion by mechanical impact is a very different thing from a wholesale explosion involving the entire mass, as would be the case with so many barrels of gunpowder; even if the bullet from one cartridge fired the cap of another there would be two separate explosions, each of which would be practically harmless, and in fact the indefinite multiplication of these separate little puffs, such as might occur, for instance, during a fire could scarcely give rise to appreciable danger. But, although there is consequently little or no risk to be apprehended from an unlimited number of safety cartridges when stored alone—as is evidenced by the quantity allowed on registered premises—it cannot be too clearly understood that it is, under certain conditions, far easier to explode a single cartridge by a fall or by a blow than by similar

means to fire gunpowder, and that the explosion of one such cartridge is sufficient to fire any quantity of bulk gunpowder that may be within reach. Thus, although the number of safety cartridges kept together in one place may not materially increase the danger,—which is at worst exceedingly remote,—the presence of bulk explosive in the vicinity entirely alters the case, and it is therefore of the first importance that safety cartridges, capped cartridge-cases, and percussion-caps should be kept at such a distance from the bulk explosive, or separated from it by so substantial a partition, that the accidental explosion of a cap, whether or not in a cartridge, cannot possibly communicate to the other explosive. Unfortunately the true significance of the above is by no means generally realised, and it is not uncommon for an inspector, whose visit is for some reason not entirely unexpected, to find the occupier of registered premises deliberately transferring his cartridges from a comparatively secure shelf to the receptacle in which the gunpowder is kept, under the impression apparently that "birds of a feather" should "flock together." A striking example of this is recorded as having occurred on registered premises in a town in Scotland, where revolver cartridges were found lying loose in a half-emptied barrel of gunpowder, and the proprietor dropped a tin box of similar cartridges on the stone floor at the inspector's feet. There were several full barrels close by, and the floor was thickly sprinkled with grains of powder!

Safety cartridges, even if filled with gunpowder, are "mixed explosives," and cannot lawfully be kept on premises registered for gunpowder only. According to the letter of the law they must be kept in a closed and secured receptacle, but in most localities cupboards, not necessarily locked, or, if the cartridges are nailed up in boxes, even open shelves behind the counter, are accepted as sufficiently fulfilling the requirements of the Act. On no account must they be exposed in the shop-window, or on the counter, or in a place where a boy could snatch them with a view to subsequent pyrotechnics at the expense of his elderly relatives.

(2) **Safety Fuzes for Blasting.**—These are of two kinds, ordinary and electric.

Ordinary Fuze.—Ordinary safety fuze, of which there are at least thirty varieties, is issued from the factory in 24 foot coils, and consists of a core of fine grain gunpowder, which, by an ingenious arrangement, is surrounded first by two layers of yarn and then by tape, pitch, india-rubber, etc., according to the purpose for which the fuze is required.

How Used.—The method of use is as follows:—A length of fuze, varying with the depth of the shot-hole or the distance of the shelter, is cut off, and one end, if the explosive is gunpowder, firmly secured in the cartridge, or, if a high explosive is to be used, in the detonator. The cartridge is then carefully pushed to the bottom of the hole, leaving the end of the fuze projecting. Tamping is now inserted, gently at first and more firmly later on, until the hole is full. The end of the fuze is now ignited and all retire to shelter until the charge explodes.

Rate of Burning.—The fuze burns at the rate of a yard a minute or thereabouts.

Risks.—The risk of explosion from safety fuze, even if badly made, is very remote. According to definition it must burn without exploding, must not contain its own means of ignition, and when burning must not communicate laterally with other similar fuze; and even if through defective material and faulty manufacture a certain amount of side spitting should be rendered possible, this could only lead to the ignition of the coil in another place, and not to explosion. In fact, the only danger to be apprehended from safety fuze is smoke; the proportion of carbon monoxide given off during combustion is considerable, and this renders the smoke peculiarly suffocating. In the year 1872 eight girls at work in a fuze factory met their deaths owing to the accidental ignition of partly made safety fuze. In this case, however, the means of escape were, it must be admitted, decidedly inadequate, and a somewhat similar occurrence in another factory has since demonstrated that with a sufficient number of escape doors there is no reason to anticipate a repetition of such a catastrophe; but it should nevertheless be borne in mind that in a confined space the danger of suffocation from the combustion of large quantities of safety fuze is by no means inconsiderable.

Instantaneous Fuze.—Safety instantaneous fuze is a special variety of safety fuze of which the core is composed of quick-match surrounded by an air space, the result being that it burns at a rate that renders it virtually instantaneous for ordinary lengths, while at the same time the minute quantity of powder, only 75 grains per yard, confines the explosion to the interior of the fuze. It is used in firing a group of shots simultaneously. From each shot-hole a length of this fuze connects the charge to the end of a piece of ordinary safety fuze. This latter is ignited in the usual way, and as soon as the fire reaches the point of junction with the instantaneous fuzes the flash is conveyed so rapidly to each charge that for all practical purposes their explosion is simultaneous. This could not be effected with any certainty by pieces of ordinary fuze, even if cut to the same length and ignited together. For this class of work, however, electricity is specially suited and is now very generally used. Instantaneous fuze is usually coloured red.

Although safety fuze may lawfully be kept in a "store," and does not in any way add to the danger of explosion, it is nevertheless, as a rule, inadvisable so to keep it on account of the dust it creates, and since it may be kept anywhere without license or registration there is seldom any material object to be gained by keeping it in a building in which scrupulous cleanliness is most desirable.

Safety Electric Fuzes.—Safety electric fuzes are electric fuzes (to be referred to later) which have been tested at Woolwich and shown by practical experiment to be so constructed that the explosion of one will not communicate with others. This test, thorough though it be, does not, however, exonerate the manufacturer in the event of an accident occurring through the explosion in bulk of a consignment of so-called safety fuzes, since the very fact of their having communicated explosion from one to another is proof positive that they are *not* safety fuzes as defined in the Authorised List. This applies equally to all the explosives in the first, or safety, division of the ammunition class, and a manufacturer who desires to take no risks would do well, therefore, to carry out occasional private tests on his own account.

(3) **Fog-Signals.**—Railway fog-signals are made in a variety of ways, but the contents, gunpowder and percussion-caps, are always the same. The following method of manufacture of what is known as a "duplex" signal will in its general features apply to all.

Method of Manufacture.—In a circular tin dish, hollow in the centre, and about 2 inches in diameter, is placed a ring of metal fitted with four nipples, on each of which is a percussion-cap, and the remainder of the hollow is filled with fine grain gunpowder. Another tin dish with a smaller hollow in the centre is now placed in the first, convex side down, and the signal is then removed to the pressing shed. Here the flanged edge of the first dish is squeezed by a screw press on to the flat surface of the other. By a simple arrangement the heavy counter-weighted arm which brings the pressure to bear interposes a screen between the operator and the signal at the instant the pressure is applied. The half-finished signal now returns to the filling shed, and in the small hollow is placed a triple nipple holding three more caps. This second hollow is now filled with gunpowder, a flat tin lid placed over all, and its flanged edge squeezed in the press, so as to form a perfectly close joint as before. The signal is thus in two parts, each quite waterproof, and complete in itself. Before issue the signals are painted and labelled. They are secured to the rail by a strip of lead soldered to the outer dish before filling. These signals are seldom or never met with in stores or registered premises, as they may lawfully be kept by railway companies for their own use without license or registration. The explosion of one will not extend to others, so their storage is free from danger.

(4) **Percussion-Caps.**—Up to the year 1898 it was thought that safety was sufficiently ensured by merely limiting the quantity of explosive in these little articles to 0·5 grain, or, if the proportion of fulminate of mercury did not exceed 25 per cent, to 0·6 grain; but in that year a terrible accident, resulting in the loss of five lives, which occurred at the London Docks during the handling of the cargo of the s.s. *Manitoba*, afforded unquestionable proof that when these caps contain anvils or when the composition is unprotected by tin-foil or similar material they are liable to explode in bulk. Since then it has been decided that a *quasi* percussion-cap cannot properly be so regarded if it contains an anvil, or if its contents are not protected by tin-foil or other suitable material. A cap therefore which does not comply with any of the above stipulations becomes a detonator, and is not entitled to the exemptions from regulation enjoyed by the properly constituted percussion-cap.

Methods of Manufacture.—Although these caps are harmless enough in the finished state, their manufacture is by no means unattended with danger, and several serious accidents have occurred at the factories in which they are made. Mixing the various ingredients to form what is known as "cap composition" has in the past been a somewhat fruitful source of disaster, and this is not altogether surprising when the extremely sensitive nature of the composition is considered. This process is now, however, carried out with little or no danger by two essentially different methods—the wet and the dry. In the former the whole of the composition undergoing treatment is kept so wet as to be virtually inexplosible, and in the latter the dry mixture is shaken up in a bag by means of a lever operated from the safe side of a steel screen so that the operator is not hurt even if an explosion occurs. The usual ingredients are fulminate of mercury, chlorate of potash, sulphide of antimony, and ground glass, but sulphur and mealed gunpowder are also sometimes used. After mixing, the composition is introduced into empty copper shells which have been previously set out on plates or "jigs," each holding about 1000, and is then pressed by machinery to the required density, and it is during the time that the sensitive powder is loose and unpressed in the shells that accidents are very liable to occur. On leaving the press the caps are varnished and covered with tin-foil, and are then ready for issue.

Division II

The second division of the ammunition class comprises those explosives which are not included in the first division, and which do not contain their own means of ignition, *i.e.* which are not fitted with an arrangement adapted to explode or fire them by friction or percussion.

Blasting cartridges, electric fuzes not included in Division I., and miners' squibs are the only explosives of this division that call for notice. Tubes, filled shells, and war-rockets are mere implements of war, and are seldom if ever met with beyond the control of the War Department, and it is doubtful if any cartridges for small-arms or fuzes for shell belonging to this division are now in existence except as curiosities.

Blasting Cartridges.—Of the three first-mentioned explosives blasting cartridges have already been referred to, and it has been pointed out that gunpowder or any other explosive when made up into packages of convenient size and shape for blasting, cannon, mines, or other like purposes, loses its name and becomes "ammunition," only to be at once by section 44 of the Explosives Act for all practical purposes reconverted into the original explosive. By this means the process of making up gunpowder into cartridges becomes an operation of manufacture which may not lawfully be carried out on unlicensed premises, and although this illicit manufacture is unfortunately still carried on to a considerable extent, it is gradually decreasing, and every effort should be made to stamp it out. Accidents due to this are reported every year, and undoubtedly many more occur which are never reported, the victims, moreover, being generally women and children. The introduction of compressed gunpowder has done more perhaps than anything else to diminish this pernicious practice.

Electric Fuzes.—Electric fuzes, and indeed all electrically fired ammunition except electric detonators, do not contain their own means of ignition, and, unless they have passed the test for admission into Division I., belong of course to Division II.

Method of Keeping.—Since, however, they do not contain exposed iron or steel, they may lawfully be kept in stores and on registered premises at the same time as explosives of Classes I. to IV. without an intervening partition, but on the other hand they may not be kept with detonators. This anomaly is no doubt due to the fact that these little cardboard fuzes are of recent introduction, and, except for use in detonators, were unknown at the time the present regulations were framed, since it is as a rule more desirable that they should be kept in the detonator "annexe" than in the main "store" with the bulk explosives. Although the quantity of explosive in each fuze is limited to 20 grains, and in many cases the explosion of one would not communicate to others, this does not alter the case, since the explosion of even one might fire the bulk explosive, and the composition employed in their manufacture may possibly be, and generally is, considerably more sensitive than an ordinary blasting explosive. As an indication of the opinion of the Explosives Department on this matter, it may be well to mention that in every license issued by the Home Office for a magazine with detonator annexe, it is expressly provided that electric fuzes are to be kept in the annexe and not in the main magazine.

How Made.—Electric fuzes are of two kinds—high tension and low tension. In both kinds the ends of the firing wires are kept apart by a small block of wood, which is then inserted in a cardboard tube and fixed there by means of sulphur. The points of the wires are embedded in a few grains of one of the various compositions that have been authorised from time to time, and which generally consist of a mixture of several of the following, viz. chlorate of potash, gun-cotton or gunpowder dust, fulminate of mercury (not more than half a grain), sulphide of antimony, and some other ingredients such as silver, platinum, phosphide of copper, and plumbago. To this priming is generally added a small magazine of gunpowder to increase the flash, but the total weight of explosive may not, as already stated, exceed 20 grains.

High and Low Tension.—In the high-tension fuze ignition is obtained by sending through the wires an electric current of relatively high voltage which causes a spark to pass between the ends embedded in the sensitive priming, and in the low-tension the same result is achieved by bridging the gap between the aforesaid ends by a fine platinum wire which is heated to incandescence by passing a current of low voltage but greater quantity. This latter method has the great advantage that, by means of a galvanometer of sufficient resistance to reduce the current below that required for firing, the circuit can be tested beforehand; but, on the other hand, owing to the delicate proportions of the platinum "bridge," a low-tension fuze is more likely to be damaged in transit and handling than one of the other kind, and moreover the high-tension are cheaper.

Miners' Squibs.—Miners' squibs are merely small paper tubes containing gunpowder, one end of each being twisted and generally tipped with sulphur. The quantity of gunpowder is limited to 1 lb. per 500 squibs. They are used in certain localities for firing gunpowder shots, and as regards storage they present fewer risks than gunpowder in bulk. German spills are very similar to the above, but are now seldom met with, and do not call for particular notice

Division III

This may be regarded as the "danger" division of the ammunition class, just as Division I. is the "safety," although there are several explosives included in Division III., such as fuzes for shell, percussion primers, colliery safety lighters, and safety firing tubes, No. 2, which, although they contain their own means of ignition, yet do not communicate explosion from one to another, and might, but for a technical difficulty, be placed in the first division.

The fact remains, however, that each explosive in the third division contains a fulminate compound, the ignition of which by friction or percussion is intended to develop an explosion, and if to this individual sensitiveness be added sufficient power either to do serious damage alone, or to communicate explosion to other similar explosives, the danger is clearly considerable.

With one or two notable exceptions, however, it is generally possible to arrange that during storage and transport the "means of ignition" can be kept separate from the explosive it is intended to ignite, so that while one, although easily fired, is too weak to do any harm, the other, though powerful enough, it may be, to sink a battleship, has had its teeth drawn, so to speak, by the removal of its "means of ignition." A filled shell, for instance, is, if securely plugged and *unfuzed*, a peculiarly safe form of explosive to store or carry about, and the fuze which converts it into a sensitive and deadly mine is of itself so feeble as to be innocuous; and the same may be said of other explosives of this division.

Detonators.—The exceptions are detonators, and electric detonators, and these are undoubtedly the most important explosives in the division, as well as being the most commonly met with in stores and on registered premises.

Up to the year 1864 nitro-glycerine, gun-cotton, and other kindred explosives had been fired only by means of a fuze or percussion-cap in the same way as gunpowder, and confinement was necessary to develop explosion. In that year Nobel discovered that by increasing substantially the quantity of explosive material in the cap nitro-glycerine could be exploded in the open and entirely unconfined, the explosion moreover being so intensely violent that a new term, "detonation," was needed to describe it. About five years later, Mr. E. O. Browne, a War Department chemist, found that by compressing gun-cotton into solid blocks this material could be similarly detonated in the open, and since then the principle has been applied to all disruptive (as opposed to propulsive) explosives in common use, with the single exception of gunpowder. Even gunpowder is alleged by some authorities to develop greater effect when fired by means of a detonator, but if this is so, it is probably merely due to the larger surface ignited and consequent increase in the rate of combustion. This detonative effect is by no means well understood, but there are undoubtedly three distinct phenomena, viz. combustion, explosion, detonation, each of which may be produced by the same explosive, but each of which requires special conditions for its development, while at the same time it is impossible to indicate the precise moment when combustion becomes explosion, or explosion detonation, except that to produce detonation shock as well as heat seems to be required. Other substances besides fulminate of mercury have this detonative property; thus dry gun-cotton will detonate wet gun-cotton, and a salt of picric acid—lead picrate for instance—will act as a detonator to the acid.

Description and Weights.—A detonator is a tube of thin copper about $\frac{1}{4}$ inch in diameter and $1\frac{1}{2}$ inches long, closed at one end and open at the other. The composition fills as a rule about half the length of the tube, and consists of fulminate of mercury, with or without other substances, such as chlorate of potash, picric acid, gun-cotton, and picrate of potash, the commonest perhaps being 80 per cent of fulminate to 20 per cent of chlorate of potash. The sizes generally met with are—

No. 3,	containing	$\frac{1}{2}$	gram of composition, or	$1\frac{1}{4}$	lb.	per 1000.
,, 6,	,,	1	,, ,,	$2\frac{1}{4}$	,,	
,, 7,	,,	$1\frac{1}{2}$	,, ,,	$3\frac{1}{4}$	,,	
,, 8,	,,	2	,, ,,	$4\frac{1}{2}$	,,	

In stores and on registered premises the weight allowed by law must be calculated *gross*, *i.e.* including the weight of the copper tubes. This is approximately as follows:—

No. 3	weighs	$3\frac{1}{4}$	lbs. per 1000.
,, 6	,,	5	,,
,, 7	,,	7	,,
,, 8	,,	$8\frac{1}{2}$	,,

Method of Manufacture.—During manufacture the utmost care is needed to avoid accident. The composition is mixed in a bag, the bottom of which can be shaken up and down by a lever passing through a steel shield so that the operator is completely screened. It is then spread over a plate perforated with 100 holes, each of which will hold the exact charge required, and by sliding this plate to one side in much the same manner as is done in the case of an ordinary Erskine loading machine, the charges are transferred to 100 tubes, which are held in a "jig" or plate underneath. The plate is now carried with many precautions to the "press," and the loose composition pressed by hydraulic pressure until quite hard and firm, when the detonators are upset into a box of sawdust and taken away to be "rumbled." This operation consists in revolving a mixture of detonators and sawdust in a drum to get rid of all loose fulminate, and when this has been done they are ready for packing in the tin boxes, holding 100 each, in which they are generally met with.

Care required.—The manufacture is on the whole remarkably free from accident, but this is undoubtedly due to the protection afforded to the work-people during each operation, and to the skill and care exercised by them.

Risks.—Unfortunately this immunity does not continue after the detonators leave the factory, and there is a lamentable number of accidents, not only during their legitimate use, but also from mischief, carelessness, ignorance, and stupidity. The bright copper capsule seems to exercise a powerful attraction, and innumerable instances are reported to the Home Office of children and others of childlike intelligence investigating the contents of these deadly little tubes with a lighted match or a pin, the only variation in the result being in the number of fingers blown off. Even in a mine or quarry subject to the special rules made under the Mines and Quarries Acts, it is not easy to exercise such strict supervision over the issue of detonators that each one can be accounted for at any given time, and in connection with railway contracts and public works, where the use of explosives is virtually unregulated by law, there is frequently no attempt at control beyond the general perfunctory instructions to be careful with explosives, the result being that the workmen supply themselves with a larger number of detonators than they require, and either carry the surplus home as playthings for their own children, or throw them away for the amusement and undoing of other people's. A well-made detonator will stand a reasonable amount of rough usage, but this cannot fairly be held to include the direct application of heat, scraping out with a knife or a pin, or crushing sufficient to cause distortion of the copper tube, any of which operations would as a rule suffice to cause explosion. The probable result of such explosion may be instructively indicated by firing a detonator under a bagful of sand or of earth free from stones, and noting the effect on the bag.

Electric Detonators.—Electric detonators are merely electric fuzes, as described under Division II., inserted into the open ends of detonators, and fixed there with sulphur in such a position that the ignition of the composition in the fuze will fire the fulminate in the detonator. They are similarly designated high or low tension, according to whether high or low tension fuzes are employed. It has been suggested to the trade that in order to avoid confusion it would be well to adopt a uniform system of marking, so that by a glance at the wires a shot firer could ascertain whether they were attached to a fuze or to a detonator, and whether for use with a high- or low-tension current, and it is hoped that the present difficulties in the way of this proposal may eventually be overcome.

Calculation of Weight.—Although, as already pointed out, in calculating the number of detonators and electric detonators to be allowed in a store or on registered premises, the *gross* weight must strictly be reckoned, there are good reasons why an inspector might use his discretion in neglecting the weight of the "leads" of electric detonators, and allotting to them the same weight per 1000 as given above for ordinary detonators. These reasons are—

(1) The insulated wire "leads," while adding to the weight, actually decrease the danger, and the longer the leads the greater the decrease—indeed, in some methods of packing, the coils of soft wire separate the detonators to such an extent as to reduce considerably the chances of communicated explosion.

(2) A single electric detonator, being closed at both ends and being easily recognisable as an electrically fired explosive, is not nearly so dangerous to the young and foolish as one of the ordinary kind, and should not therefore be unduly handicapped in regard to storage facilities.

Apart from factories and magazines licensed directly by the Secretary of State, detonators and electric detonators may be lawfully kept in the following ways:—

Methods of Keeping.—(1) In a "store" entirely appropriated to them, the quantity kept being in accordance with that specified in Order in Council No. 6, for the division under which the "store" is licensed,—the gross weight being reckoned.

(2) In an "annexe" to a "store" in which other explosive is kept. The "annexe" should be of similar construction to the "store," and situated a yard or two away. The gross weight of detonators is included in the total quantity of explosive allowed in the "store."

(3) When only a limited number are required for the use of a colliery or quarry or other similar enterprise, the requirements of the Explosives Act may, in many cases, be deemed to be adequately observed if the detonators are kept in a secure cupboard attached to the wall of the "store" between the inner and outer doors in such a position that the cupboard can only be

conveniently opened when the inner door of the "store" is shut. This method should only be permitted in cases where the detonators or electric detonators are ordered by the occupiers in quantities not exceeding 500 at a time, so that the total quantity is always well under 1000.

(4) On registered premises well isolated from other explosives. A colliery or quarry office or other convenient building may, for instance, be registered, and 15 lbs. gross weight of detonators kept therein in a locked box or drawer. Or, if a small building suitably situated and constructed is exclusively appropriated to such keeping, the quantity may be 60 lbs.

(5) For private use, and not for sale, 100 detonators may be kept in any suitable place subject to a police certificate issued under Order in Council No. 12.

Cartridges for Small-Arms.—The only other explosive in this division which calls for passing mention is that which comes under the heading "Cartridges for small-arms." In order to belong to the third division of the ammunition class these cartridges must not be safety cartridges, and must contain their own means of ignition. There are certainly no cartridges for small-arms in common use which fulfil these conditions, and indeed it is doubtful if any such are in existence. Those used in punt-guns for wild-fowl shooting, containing, as some of them do, 4 oz. of powder, may possibly belong to this division, but they are so seldom met with that the question has never been raised, and probably never will be. It is as well, however, to bear in mind that such things are occasionally used, and that if found they should not be granted without question all the privileges attaching to safety cartridges. They are about nine inches long and over an inch in diameter.

CHAPTER VIII

Class VII.—Firework

Definition.—This class has two divisions.

The first division consists of firework composition only, and no explosive of this division is authorised for general sale. Hermetically closed canisters of coloured fire, containing not more than 1 lb. each, are, however, expressly removed from this division and placed in the second.

The second division comprises all manufactured fireworks—that is to say, all explosive when enclosed in a case or contrivance, or otherwise adapted for the production of pyrotechnic effects, signals, or sounds.

Thus articles such as "aluminium torches" and "lightning paper," although not enclosed in a case or contrivance, are "otherwise adapted" for the production of a pyrotechnic effect, and are consequently manufactured fireworks. Bengal matches, on the other hand, being merely ordinary flaming fuzees with a little colouring matter added, are held by the Explosives Department to be matches and not fireworks. Although the correctness of this view may not be unassailable, the effect of it is to prevent the keeping of these articles in the same receptacle as fireworks, and as they are as sensitive to ignition by friction as ordinary matches, this result is most desirable. In the absence, therefore, of a contrary ruling, there would seem to be no good reason to depart from the practice which has now been very generally adopted of regarding them as matches pure and simple.

Illegal Manufacture.—It is not proposed to give any details in regard to the manufacture of fireworks. There are already too many unlicensed pyrotechnists, chiefly amateurs, in spite of the heavy penalty of £100 a day attached to this breach of the law, and it is most undesirable that they should be encouraged or assisted by an explanation of the methods adopted by the principal makers. An instance occurred only a short time ago of a young and promising life being sacrificed during the preparation of home-made fireworks, and it came to light at the inquest that there was an open keg of powder under the bench on which the manufacture was being carried on, and that the unfortunate operator was probably smoking at the time.

Another point in connection with amateur pyrotechny is that, apart from the risk of accident due to carelessness, there is the additional danger arising from the fact that, in the majority of recipes available to the amateur, the admixture of chlorate of potash and sulphur is freely recommended, and this may very possibly lead to spontaneous ignition, and is consequently expressly forbidden by Order in Council.

Risks.—Fireworks are not as a rule individually dangerous; hence the immunity from accident during 5th of November displays at schools and private houses, where Roman candles, squibs, crackers, rains, wheels, etc., commonly known as "shop" goods, form the principal fare, and are scattered about promiscuously. Danger arises only when a substantial quantity of such goods is present in one place. There are some kinds, however, of which a single one is capable of doing serious mischief if fired accidentally or without proper precautions; and although these are not generally found on registered premises, they are to be met with in "stores," and are not specially prohibited in any case where ordinary "shop goods" may lawfully be kept. The following is a list of these more dangerous fireworks, but as the same article is frequently known by various names according to the maker, it is by no means claimed that the list is a complete one :—

Aerial maroons.
Devil-among-the-tailors.
Feu-de-joie.
Infernals.
Jack-in-the-box.
Large gerbs.
Large squibs.
Maroons.
Maroon rockets.
Mine of crackers.
Mine of serpents.
Rockets.
Shells.
Skimmers.
Tourbillons.
Volcanoes.
Water-devils.

Socket Signals.—In addition to the above, which are all true fireworks, there is a class of goods known as socket signals which are not used in pyrotechnic displays, but which are nevertheless fireworks within the meaning of the Explosives Act, and which have been peculiarly prolific of accidents. These are to be found in marine stores in seaport towns, and the attention of the local inspector is specially directed to them. The Board of Trade requires that every vessel clearing from a British harbour should carry a fixed number of such signals. They are fired from a small mortar or "socket" fixed either to the deck or to the taffrail, and are intended to burst at a height of 100 feet or more.

Description of a Sound Signal.—The "sound" signal is perhaps the worst offender, and consists of a stout tin canister about 5 inches long by 1½ inch in diameter, coned at one end. In the base is the propelling charge of gunpowder, lighted by a strand of quick-match which protrudes from the "socket." The charge, besides firing the canister up into the air, ignites a fuze which is attached to a detonator embedded in about 4 oz. of gun-cotton or cotton powder, the fuze being of such a length as to fire the detonator at the highest point of flight.

Risks.—The effect of firing this on the ground instead of in the air may well be imagined, and yet this is how accidents have been frequently brought about. At Lossiemouth in June 1900 a lighthouse-keeper, who ought to have known better, fired one of these signals from a hole scooped in the ground in a place of public resort, the result being that one person was killed and seven injured.

Again at Bootle in June 1902 a foreign sailor fixed one of them between two stone setts in the street and fired it. It exploded about six feet from the ground, killing one person and injuring sixteen others.

At the inquest held in connection with this case it transpired that although socket signals are most carefully looked after so long as they form part of a ship's equipment, by the Board of Trade regulations they must be replaced by fresh ones every two years, while there is no obligation to destroy those which are discarded. The result of this appears to be that it is quite easy for any member of the ship's company to obtain a signal or two at any time,—with consequences as above related.

Moreover the two most dangerous ingredients of these signals—fulminate of mercury and gun-cotton—are peculiarly unaffected by water, and a bad accident was caused in May 1901 by one of them which was picked up by a gipsy's son at the bottom of a dried-up pond at West Thurrock, and which had probably lain there for some considerable time. The finder took it home and gave it to his father, who threw it on the fire, when it exploded, killing a child and injuring two other persons.

Toy Fireworks.—What are known as "toy fireworks" have called for and have received special treatment. These comparatively harmless little articles, each of which contains the minutest quantity of explosive, could not, without hardship to a very needy class of the population, be treated in the same way as ordinary fireworks, and special relief from restriction has from time to time been afforded to those engaged in the industry. In the first place, the quantities of explosive used being so small, there is no objection to the manufacture being carried on in a dwelling-house, and factory licenses, at a merely nominal fee, have consequently been issued to allow these goods to be made in one or two rooms of the houses occupied by the licensees, provided the total weight of explosive present at any one time does not exceed twenty-four grains, of which not more than eight grains may be in any one place—an amount which could scarcely give rise to a serious accident. In the next place, the London County Council, who are the Local Authority under the Explosives Act for the Metropolis, have decided not to require registration of premises on which only "toy fireworks" are kept, provided the amount of each does not exceed the following:—

Amorces (paper caps)—3 dozen boxes of 100, or 6 dozen boxes of 50.
Coloured fire—3 dozen 1d. boxes, or equivalent in smaller boxes.
Throw-downs—3 gross (12 dozen to the gross).
Christmas crackers—unlimited.
Lightning paper and other "toy" fireworks in very small quantities.

And their example has been followed by the Corporations of several of the largest boroughs in the kingdom. Although, strictly speaking, this is a breach of the exact letter of the law, the Home Office authorities have not thought it necessary to interfere.

Christmas Crackers.—A practice has, however, lately arisen of introducing small fireworks into Christmas crackers. In the first instance, articles on the borderline of fireworks, such as "Pharaoh's serpent" and "fern leaves," were found to be very popular and to lead to heavy sales; but variety was needed, and so it gradually came about that the border-line was overstepped, and eventually such unmistakable fireworks as Catharine wheels found their way in, with the natural result that it became necessary to issue an authoritative statement as to which articles might be freely inserted into these toys, and which would require registration of the premises. The following lists, which are liable to alteration from time to time, represent the views of the Explosives Department on this question, and in the event of a local inspector finding in a Christmas cracker anything of the nature of a firework which is not included in one or other of these lists, he should send a description of it to the Home Office and ask for instructions.

The following may be introduced into Christmas crackers without requiring registration of the premises on which they are kept:—

Magnesium wire.
Fire balloons.
Fern leaves.
Serpents' eggs or Pharaoh's serpents.
Japanese scintillettes.
Crack-shots.
Throw-downs.

The following may *not* be so introduced:—

Catharine wheels.
Lightning paper.
Coloured stars.
Aluminium torches.
Miniature fireworks such as squibs and lances.

Keeping with other Explosive.—Fireworks may not be kept in a "store" or on registered premises at the same time as gunpowder or other explosive of Classes I. to VI. unless there is an intervening partition of the character set forth in Orders in Council Nos. 6 and 16, and if kept on registered premises with other explosive, even with an intervening partition, the total weight of *all* the explosive on such premises may not exceed 15 lbs. in Mode B, or 60 lbs. in Mode A, and in addition 500 lbs. of explosive contained in ammunition of the first (safety) division. Thus a gunmaker is practically prevented from dealing in fireworks, unless he has more than one place of business, and a dealer in fireworks cannot conveniently carry on a trade in gunpowder or cartridges. This was no doubt fully intended by the framers of the Act; in spite of all precaution some natures of coloured fireworks are not entirely free from the risk of spontaneous ignition, and their presence at the same time as gunpowder on premises situated perhaps in a crowded neighbourhood is unquestionably objectionable. This point is fully explained in the Guide to the Explosives Act, but there is so much misunderstanding on the matter that repetition will do no harm.

CHAPTER IX

GENERAL OBSERVATIONS

THERE are doubtless many retail dealers in explosives, and others, who consider the majority of the legal restrictions imposed by the Explosives Act superfluous and vexatious,—although, happily, there are indications that the more is known of the subject the more the necessity for legislative control is appreciated,—and in order, therefore, to assist local inspectors to hold their own in any discussion that may arise, and to justify any proceedings they may deem it right to institute in the police court, it is proposed in this concluding chapter to offer a few general observations on the various risks to be met with in connection with the storage of explosives, and on the methods to provide against them adopted in the Act. It is hoped, moreover, that the suggestions and examples will not be entirely without value to mining engineers, quarry owners, contractors, and other large users of explosives.

Construction of Place of Storage.—The place in which the explosive is kept, whether it be a duly licensed "store," a small building registered for keeping in Mode A, or merely a "receptacle," Mode B, must be of stout construction and be fitted with one or more good locks. Moreover the locks must be used, the somewhat common practice of locking a powder safe or other receptacle and leaving the key in the lock being so manifestly absurd as to require no comment. "Stores" are best made of concrete, with arched roof of the same material, but there is no objection to good hard bricks set in cement, with a slate roof. The doors must be of especially stout construction, as being, as a rule, the most obvious point of attack. In the "piping times of peace," when the interests of masters and men are the same, the necessity for such a solid type of building may in the case of a mine or quarry appear somewhat superfluous, but in time of war, *i.e.* when a strike unfortunately breaks out, and the men are ready to seize any weapon that may offer a convenient and easy method of wrecking their employers' property, there is comfort in the knowledge that the dynamite is securely enclosed between four stout walls. It is not generally known that at the time of the dynamite scares in 1883 the question was raised as to the advisability of posting a sentry on every magazine in the kingdom.

Only a few months ago the magazine belonging to the burgh of Perth was broken into by a tramp, and a fire lit in the porch, fortunately without result.

But it is no use strengthening the walls and doors if keyholes and ventilators are left wide open to invite the introduction of matches or fuzees by mischievous children, and care should therefore be taken to cover the keyholes on the *inside*, and to construct the ventilators so that they take a zigzag direction through the walls, each end being covered by a stout grating of small mesh. In an isolated situation a "store" should be surrounded by a good fence, difficult to climb, and of such material as not to conceal the movements of a person trying to effect an unlawful entrance.

Excess of Legal Quantity.—It is most essential that the quantities of explosive allowed by law in "stores" and registered premises should not be exceeded, and any infringement of this rule should, unless there are very specially extenuating circumstances, be regarded as unpardonable and visited with extreme rigour. The weight of explosive allowed is regulated by the distances from "protected works" that actual experience has shown to be necessary if danger to life is to be avoided, and the result of an excess may well be that persons fairly entitled to regard themselves as safe may be brought within the zone of danger.

Exclusive Appropriation.—Another point of importance is that the building or receptacle, as the case may be, should be entirely appropriated to the keeping of explosives. This may be deemed to include a reasonable number of empty cases, and the tools and implements used for opening the cases (this applies to a "store" only), and for sweeping out.

Exclusion of Grit, etc.—Every care must be taken to keep the building or receptacle clean, and to prevent the explosive coming in contact with iron, steel, or grit. This is usually taken to mean that in the case of a "store" or building registered for keeping in Mode A, the building must be lined with wood and have a wooden floor, but this is by no means compulsory. "Neat" cement, *i.e.* cement unmixed with sand, if well painted, makes a capital lining, and there is no objection to the floor being made of asphalt free from grit. An uninflammable material called "uralite," largely composed of asbestos, is also to be recommended for the lining of the walls and roof. Again, lead, zinc, or raw hides can be used to cover the floor. If wood is employed for the lining, a coat of varnish is strongly to be recommended.

In spite of every precaution there are undoubtedly a considerable number of accidents caused every year by the presence of grit in contact with explosive, and the risk is much accentuated if iron or steel is also present, on account of the facility with which a spark can then be produced. In a quarry bore-hole grit must always be present, and is unquestionably the cause of many an accident during the ramming home of a charge even when a wooden rammer is employed; but in a magazine or store, or even on registered premises, there is no reason why measures should not be taken to render the presence of grit almost impossible. The soles of boots that have been in use for some time invariably contain hard gritty particles, and should never be placed on the floor of a store without protection in the shape of overboots or shoes. A footboard about six inches high across the inner door is also advisable,—this should slide up and down between pairs of battens on the door-posts so as to be easily removed when the floor is swept.

Iron and steel, on account of their hardness, are dangerous companions for explosives. This is now generally acknowledged by the most reckless of miners and quarrymen, and even in works not regulated by special rules it is seldom that an iron or steel stemming-rod is allowed; but it is to be feared that as a result of this a feeling has gradually arisen that no danger whatever is to be anticipated from the use of copper, brass, or other soft metal. This is of course quite wrong; a more violent blow is required to fire a film of explosive between brass and copper surfaces than is the case between surfaces of iron or steel, but the difference is merely one of degree, and no more force than is needful should be used either to ram home a charge or to open a barrel whatever the material of the tool.

Cleanliness.—Perfect cleanliness is also most important, and the interior of a "store" or of a receptacle containing explosive on registered premises should be thoroughly swept and garnished. Cobwebs do not of themselves do any harm, but they may conceal grit or grains of powder and should be rigorously excluded. At St. Ives, Huntingdon, in May 1898, two lads were killed by the explosion on registered premises of a powder safe, and there is good reason to believe the accident was due to loose powder and grit in the hinge of the safe, or to one of the deceased treading on spilt powder. The house was wrecked and the adjacent buildings much damaged. Again at Wigan, in September 1901, a mining engineer, who was also agent to an Explosives Company, lost his life by the explosion of a powder safe. Before he died he was able to make a statement to the effect that having struck a match to find the keyhole he threw it down in front of the safe *without even blowing it out.* No doubt the safe was partly open at the time, and loose powder had been spilt on the floor and had not been swept up.

But these are only two instances out of many, and there is little doubt that want of cleanliness is one of the most prolific causes of accidents in connection with the keeping of explosive.

Lightning.—Protection from lightning is the next matter to consider, and inasmuch as in the days before the introduction of lightning-conductors a remarkable number of explosions appear to have been caused by this agency, and since a well-built and properly managed magazine or "store" can hardly be blown up by any other means, the subject is undoubtedly of great importance.

A store of Division B, C, or D must be fitted with a lightning-conductor. It is not easy to specify the exact measure of security obtained by the erection of a conductor, but authorities are generally agreed that a bad one is worse than none. Moreover a conductor which would give a high degree of safety in the case of a cathedral or other public building, where side flash or short circuiting through a chance conductor in the interior of the building would not be of any material consequence, might very possibly afford no protection at all to a magazine or store filled with explosive. According to Sir Oliver Lodge, iron is a better material for a conductor than copper, on account of the smaller liability to side flash, but the very quality that produces this advantage, viz. its lower conducting power as compared with copper, renders it necessary to employ thicker rods. Again, iron does not "weather" so well as copper, but, on the other hand, it does not offer so much temptation to thieves and marauders. In erecting a lightning-conductor the following points should be observed :—

(1) All sharp angles should be avoided. Thus a single terminal in the centre of the ridge of a span roof with the conducting tapes leading along the ridge and down each end of the building, and so to earth, is bad, but unfortunately not uncommon.

(2) All conducting material such as rain gutters and iron doors should be connected to the conductor or direct to earth.

(3) The terminals should be raised as high as practicable, and the more there are of them the better.

(4) The "earth" or "earths" should each consist of a copper plate about a yard square bedded in coke and planted deep enough to ensure the constant presence of moisture. This should be easily managed in this country; but in South Africa, for instance, where moist soil cannot always be found at a reasonable depth, a shower of rain has been known to reduce the resistance of a lightning-conductor from 20 ohms to zero.

Perhaps as good a form of conductor as any is an arrangement of two rods or tapes each separately earthed and supported by a pole a few yards from either end of the building, and joined together by a few strands of stout barbed wire a foot or two above the ridge. The end of each terminal should be fitted with three or four points. The arrangement should be annually tested for conductivity, and occasionally for resistance also, and this should not exceed 15 ohms; in Government buildings 2 ohms is usually the limit.

Repairs.—It is manifestly imprudent to carry out any work in the nature of repairs in the immediate neighbourhood of explosive material, and "stores" should be emptied of their contents and thoroughly cleaned out before any such work is undertaken. It is not difficult to choose a time to do this when the stock is low, and to provide temporary protection for the small quantity of explosive that may remain.

Exclusion of Water.—Care must be taken to exclude water from a place in which it is proposed to keep ungelatinised nitro-glycerine compounds such as common dynamite and carbonite, since, as already stated, these materials readily part with nitro-glycerine in contact with water. Gunpowder and ammonium-nitrate explosives are also, no doubt, affected by water, but are merely rendered useless.

Definition of a Grown-up Person.—The regulation prohibiting any one under sixteen years of age from entering a store unless under the supervision of a "grown-up person" is somewhat vague. Taken in its most literal sense a "grown-up person" is presumably one who has stopped growing; but since time alone can show this the above rendering is not well suited to a court of summary jurisdiction such as a police court! Again, many a lad of eighteen or so is more "grown-up" from the point of view of the Explosives Act than a man of mature years with a well-cultivated taste for whisky. This matter is, however, fully dealt with in the official "guide," and the view there expressed should be generally adopted. It should be noted that there is no legal objection to a growing lad of sixteen going alone to a store, but he must not be accompanied by a companion below that age.

Store-Keepers.—While on the special subject of stores, it may be well to point out that, unlike registered premises where the responsible manager is, as a rule, not far away for long at a time, the observance of the many and important rules regarding the introduction of fire, matches, steel, grit, and so on, is in the hands of the store-keeper, who is generally either the carter employed in carrying the explosive to customers, or, in the case of a mine or quarry, a labourer with no special knowledge of explosives, and much depends on his individual trustworthiness. He should, however, be definitely ordered to search his own pockets for matches and smouldering tobacco before entering the store, and should train himself to do so automatically. Overshoes should invariably be provided, and the store-keeper should never enter the building without using them. In this connection it may be pointed out that although it is not obligatory for the occupier of a store to submit Special Rules for the sanction of the Secretary of State, he can do so if he chooses, and can then proceed against the store-keeper in case of the non-observance of a rule and have him fined up to forty shillings. It should be noted, however, that there is no prohibition of the introduction of an artificial light of a character which does not cause danger of fire or explosion. An electric lamp with covered-in switch, or an ordinary carriage lamp burning a candle, would neither of them be objectionable.

Rules and Notices.—In addition to the abovementioned Special Rules (if submitted and sanctioned) a copy of the General Rules, as set forth in Orders in Council, Nos. 5 and 6, should also be posted, together with a notice to indicate the quantity of explosive allowed in the store. It is seldom indeed that this regulation is attended to, but it is one in respect to which managers and owners would be well advised to regard with a more friendly eye, as even if the notices are not read the fact that they are posted in a conspicuous position relieves the management of considerable responsibility, since a plea of ignorance on the part of a negligent store-keeper is hereby rendered inadmissible.

Registered Premises.—There are now a few points in connection with keeping explosives on registered premises in Mode A or Mode B which call for separate mention.

Construction.—In the first place, the building erected for keeping in Mode A may be of iron, a material which is not admissible in the case of a store. Thus stout corrugated iron sheets lined with wood may be employed, provided the situation or other conditions are such as to prevent the access of unauthorised persons.

Situation.—The building must be detached from a dwelling-house, but no definite distance is specified. From a highway or public place, however, a *safe* distance must be observed. Since a store of A division has to be 25 yards from a highway and may contain 300 lbs. of gunpowder, it may fairly be taken that a building registered for keeping in Mode A, in which 200 lbs. of gunpowder may be present, should observe a distance of two-thirds of 25 yards, *i.e.* 16 yards.[1] It is probable that a shorter distance even than this was contemplated when the Explosives Act was framed, since a dwelling-house is relatively so poorly protected; but it must not be forgotten that under the old Gunpowder Act of 1860 any person posing as a dealer could keep 200 lbs. of gunpowder under no restrictions whatsoever, so that the net gain in safety to the public is considerable. The above estimate of 16 yards must, of course, be regarded merely as a guide, since, in the event of the distance being practically proved to be insufficient for safety, the responsibility must rest on the occupier of the premises.

As regards Mode B it is provided that the receptacle containing the explosive may be placed in a dwelling-house or in any other building, such as a warehouse or storeroom, not exclusively appropriated to the keeping of explosive, and therefore not qualified for keeping in

[1] This applies only in cases where the highway is unprotected from the building. When a shop or dwelling-house intervenes, the protection afforded will in most cases be sufficient, whatever the distance.—EDITOR.

Mode A. A little building or a fireproof safe situated in a warehouse, which warehouse by reason of its construction or appropriation is not qualified for Mode A, may strictly only be used for keeping in Mode B; but, as pointed out in the Guide, there are occasions where such a building or safe may be regarded as quite suitable for Mode A storage.

Precautions.—No explosive may be kept in a fireproof safe except gunpowder and small-arm nitro-compound. The evident intention is to exclude blasting explosives, especially those containing nitro-glycerine. It is by no means uncommon to find safety cartridges in the same safe as gunpowder; this of course is contrary to law, and nullifies the whole object of the fireproof safe, which is to prevent the heat from the fire or explosion of an easily ignitable body from reaching the gunpowder.

Highly inflammable articles must be kept at a safe distance from explosive. This rule would appear to be almost superfluous, but there are unfortunately many instances in which accidents have occurred from its infringement. Not so very long ago at Chard in Somersetshire considerable damage was caused by the explosion of a quantity of gunpowder in a small detached building behind an ironmonger's premises. On investigation it transpired that the building was also used as a benzoline store, and that the explosion was due to the accidental ignition of the benzoline. It is most important that the difference between an "explosion risk" and a "fire risk" should be clearly understood, and the above is a good example of this. Good ventilation, a few yards interval, and a well or trench to prevent outflow, render even a highly inflammable liquid quite incapable of doing damage beyond its own immediate surroundings *even if ignited*, and moreover there is, as a rule, plenty of time for the occupiers of the premises to escape; but an explosive may at a moment's notice exert a destructive effect over a considerable area, and where for public reasons it has not been deemed advisable to render compulsory the maintenance of a "protected" zone, it is all the more incumbent on occupier and inspector alike to disregard no precaution which may by any possibility decrease the chance of accidental ignition. In the instance quoted above there was every reason to believe that the occupier of the premises was honestly actuated by a desire to adopt the safest method of storage, but a little further consideration would have shown him that by keeping the two substances together he had vastly increased the risk of accident.

Breaking Bulk.—Except in the filling-room, bulk must not be broken on registered premises except to the extent of one package holding not more than one pound. That is to say, a dealer should obtain his gunpowder, whether sporting or blasting, in 1 lb. tins or bags, or he may find himself in the position of being unable lawfully to serve a customer. A very little loose powder is far more likely to lead to an accident than a considerable quantity in closed packages, and if for the purpose of selling ounces it is found necessary to keep a 1 lb. tin unclosed it is strongly recommended that this tin should be kept in a drawer or cupboard away from the main supply.

Definition of "Premises."—In framing the law regarding registered premises it was manifestly most necessary to define the scope of the word "premises," and this has accordingly been done in section 27 of the Act. All buildings and places adjoining each other and occupied together shall be deemed to be the same premises. Thus two shops next to one another and occupied by the same person count as one, and in a town or village this is the only feasible method; but in quarry and mining districts the strict enforcement of this section may lead to undoubted hardship, and it is for the consideration of the inspector whether he should take exception to the establishment on extensive properties of as many depots of explosive, each containing the quantity allowed on registered premises, as can be conveniently arranged, provided they are at a safe distance from one another and that each satisfies the conditions required for Mode A or Mode B as the case may be.

How to Destroy Explosives.—It occasionally happens that owing to forfeiture or for other reasons it may be found necessary to destroy explosive, and the following methods should then be adopted:—

Gunpowder should be thrown into water—preferably hot water—which dissolves out the saltpetre and renders the explosive harmless. An alternative method is to lay it out in a train and fire this from one end by means of a piece of safety fuze; but if more than one train is laid, care should be taken to lay the second at such a distance from the site of the first as to run no risk of its being fired by the heated soil, as many serious accidents have occurred in this way.

Nitrate of ammonium explosives should be scattered on damp soil. These are so hygroscopic that even on a dry summer's day a short exposure to the air renders them harmless, but it is generally easy to find a ditch damp enough to take immediate effect. If not too generously applied these explosives make an excellent manure.

Gelatines, dynamite, carbonite, and in fact all other blasting explosives are best destroyed in the following manner:—The cartridges should be removed from the packages and laid out in a train on a piece of waste land at an angle of 45° to the direction of the wind. They are then well soaked with paraffin and the weather end of the train ignited by a length of safety fuze or by other suitable means which will allow time for the operator to get to shelter. The explosive will, according to experience, burn away without explosion.

Detonators should, if practicable, be taken out to sea and thrown overboard in deep water. If this cannot be done it may be possible to find a suitable place where they can be fired in batches, but this should not be done by a local inspector without reference to the Home Office. On no account should detonators be thrown into ponds or streams.

In Appendix A will be found a summary of some of the chief explosions that have taken place at various times, ancient and modern. It need scarcely be pointed out that in Table II. the details are more trustworthy than in Table I.

In addition to the documents on sale by His Majesty's printers, of which a list is given in the official Guide, there are numerous memoranda and circulars which have been issued by the Explosives Department from time to time in connection with special questions. A list of these is given in Appendix B, and copies may be obtained on application to H.M. Inspectors.

APPENDIX A

In Table I. a few examples are given of disastrous explosions in times gone by, with the object of showing the results that may be expected from the explosion of comparatively inconsiderable quantities of gunpowder in the immediate vicinity of brick and masonry structures. In the original list, compiled in the year 1875, by the late Sir V. D. Majendie, a noteworthy feature is the number of explosions caused by lightning. With regard to the numbers of killed, Sir Vivian points out that in three instances the number is set down as 3000, and that "there is a roundness about this number which suggests grave doubt as to its accuracy." He also mentions, however, that the details given relative to the explosions at Leyden and Eisenach are "well authenticated." His list comprises no less than 93 explosions—22 of which are definitely attributed to lightning.

In Table II. the distances are given at which structural damage, serious or otherwise, has been caused by varying quantities of different explosives. The figures are as a rule reliable, but the greatest quantity amounts to no more than 200 tons, and was possibly considerably less. Serious structural damage signifies such damage to substantial buildings as would imperil the lives of the occupiers.

TABLE I.

Date.	Place.	Damage to Property.	Remarks.
4.1.1649	London, Tower Street .	60 houses demolished .	37 barrels of gunpowder exploded in a shop.
1654	Gravelines .	?	Explosion of a magazine ; 3000 persons are said to have been killed.
1693	Dublin .	?	218 barrels of gunpowder exploded ; 100 persons killed.
10.9.1739	Bremen .	1000 houses demolished	Caused by lightning ; 40 persons killed.
18.8.1769	Brescia .	?	Caused by lightning ; 3000 killed.
1772	Trichinopoli .	Town destroyed and foundations shaken	340,000 ball cartridges also discharged.
1773	Abbeville .	100 houses destroyed .	Caused by lightning ; 150 persons killed.
1792	Poland, Lubau	Two synagogues and a great number of houses destroyed. All the windows in the town broken	The axle-trees of 10 gunpowder waggons, conveying powder to the army, took fire.

1794	Grenelle, near Paris	All adjacent buildings destroyed	Powder mills blew up, and 3000 persons are said to have been killed.
Jan. 1807	Leyden	About 300 houses in the best part of Leyden destroyed	Explosion of a gunpowder ship in the Rapenburg Canal; 200 killed.
Sept. 1810	Eisenach	28 houses destroyed and town set on fire	Spark from horse's hoof set fire to spilt powder, and three powder waggons blew up; 54 citizens, besides the escort, killed.
1857	Bombay, Joudpore	?	Lightning; about 1000 persons killed.

TABLE II

Date.	Place.	Quantity and Nature of Explosive.	Structural Damage.		Remarks.
			Serious.	Slight.	
1864, Oct. 1	Two magazines belonging to J. Hall and Sons and the Lowood Gunpowder Company respectively, and situated on the river bank at Erith	57 tons of gunpowder	*See* remarks	$2\frac{1}{2}$ miles	13 persons were killed on the spot, and doubtless many of the injured died later. The damage varied considerably, according to the position of the building damaged, thus :— *At* 70 *yards*, there were two cottages ; these were demolished. *At* 100 *yards*, a dwelling-house was demolished. *At* 680 *yards*, a magazine belonging to Curtis and Harvey. The door was open and men at work. Walls cracked, windows broken, and a piece of iron driven through roof. *At* 1300 *yards*, Erith Parish Church, on same level. Sashes forced in and ceiling down. *At* 1600 *yards*, gasworks and cottages on same level. Windows broken. *At* 1 *mile*, Belvedere Station and many houses on same level. Window frames and shop fronts blown in and walls cracked.

					At 1¼ *mile*, and on brow of hill. Building much damaged, doors and brickwork forced in. *At* 1¾ *mile*, on brow of hill. Building seriously damaged, and 10 unfinished cottages fell down next day. There were no sashes broken beyond 2½ miles, but window glass was broken up to 10 miles. The river wall, on which Hall's magazine stood, was blown away for a distance of 50 yards, and 40 yards more was badly injured. Unfortunately, Colonel Boxer, when reporting on this accident, does not state the quantity of powder in each magazine, although he asserts that the Lowood magazine was probably blown down prior to the explosion of the powder contained in it. The quantity of gunpowder responsible for the damage is thus probably largely reduced. The ground was covered with débris over an area of 600 yards radius, and ignited wood was thrown to a distance of 1 mile.
1871, Aug. 11	Stowmarket, Suffolk	13½ tons guncotton	Yds. 466	¾ mile	24 persons were killed and over 50 injured. Cottages at 300 to 400 yards were practically destroyed. Windows were broken up to 4 miles and sashes up to 1 mile.
1874, Oct. 2	Barge on canal in Regent's Park, London	5 tons gunpowder	200	Yds. 400	Window sashes were broken up to 600 yards. The canal banks no doubt acted as a screen.

Date.	Place.	Quantity and Nature of Explosive.	Structural Damage.		Remarks.
			Serious.	Slight.	
			Yds.	Yds.	
1879, Feb. 21	John Hall and Son's Powder Factory at Faversham	3½ tons gunpowder	200	900	The buildings damaged at 900 yards were in an elevated position.
1883, Jan. 19	Minden, Holland	30 tons gunpowder	...	...	Explosion travelled from one building to another. The buildings were 50 metres apart. The town of Minden, at 1 kilom., was not injured. 12 persons killed.
1889, Sept. 6	Antwerp .	About 6 tons gunpowder (estimated)	370	1000	This is not of much value, as the quantity of powder was estimated from the radius of damage. About 90 persons were killed and 150 injured.
1890.	Wohn, China .	Several hundred barrels	?	?	1000 houses are said to have been destroyed, and about 350 persons killed.
1891, Apr. 23	Vigna Pia Magazine, Rome	285 tons gunpowder	875	1650	A window built up with masonry, at 5000 yards, was blown in.
1892, Sept. 3	Barque *Auchmountain*, off Greenwich	20 tons gunpowder	?	?	A house at 1¼ miles was uninjured.

1893, Nov. 3	Santander, Spain	28 to 33 tons of dynamite	?	650	About 500 killed and 2000 injured. Local havoc tremendous. Pieces of heavy iron rails were projected over a mile—one account states an anchor was thrown to a distance of 2 kilos.
1894, May 7	Waltham Abbey	3700 lbs. nitro-glycerine	85	900	Although the cordite factory was situated only from about 60 to 300 yards away, and was in full work, and although many of its buildings were greatly shattered, not a particle of cordite even took fire, much less exploded.
1895, Nov. 28	Leewfontein. S. Africa	25 tons dynamite	?	?	An underground magazine in the dynamite factory. A large clock in a cottage 3 miles away was thrown down. All the other magazines were demolished, but without exploding the dynamite in them.
1895, Mar. 19	Keeken, Germany	22 tons dynamite and blasting gelatine	?	1310	Two vessels at 23 to 25 yards had their decks smashed in. One building was cracked and fissured at 1310 yards, window frames were smashed at 2400 yards, and glass broken up to 15,000 yards.
1896, Feb. 19	Johannesburg, S. Africa	55 tons blasting gelatine (train-load)	660	1000	The buildings round were of corrugated iron and mud only, and they were consequently quite demolished up to a radius of 330 yards. Pieces of iron were picked up at over 3000 yards. Over 50 persons were killed.
1896, Oct. 2	Buluwayo, S. Africa	20 tons dynamite	?	?	A crater was formed 60 feet across and 15 feet deep. Much damage to surrounding buildings.

Date.	Place.	Quantity and Nature of Explosive.	Structural Damage.		Remarks.
			Serious.	Slight.	
			Yds.	Yds.	
1897, May 24	Krummel, Germany	13,200 lbs. dynamite	?	1100	Only about 11,000 lbs. exploded simultaneously. Tiles were displaced and windows broken up to 7600 yards.
1899, Mar. 5.	Toulon . .	200 tons of gunpowder and smokeless	250	3500	Window frames were broken up to 7650 yards, and heavy débris projected 2187 yards. A second magazine, 150 yards away, was little injured. The magazine that exploded was mounded. A large quantity of smokeless was found unconsumed, so that the quantity might have been considerably less than 200 tons.
1901, Apr. 25	Griesheim, Frankfort-on-Maine	7 or 8 tons of picric acid	?	1100	24 persons killed and about 190 injured. According to the account received through the F.O., houses were unroofed and walls blown down at Schwannheim, 1100 yards away, but either this is incorrect or the quantity of explosive was considerably greater than we have reason to suppose.

APPENDIX B

List of Documents which may be obtained on Application to H.M. Inspectors of Explosives, Home Office, Whitehall, S.W.

1. Memorandum for Inventors.
2. Memorandum as to Coloured Fires and Bengal Matches.
3. Memorandum as to the Permitted List Test for Explosives for Use in Coal-Mines, dated 14th February 1903.
4. Application for Testing Explosives for Use in Coal-Mines.
5. Code of Rules for the Erection of Lightning-Conductors.
6. Circular Letter as to the Testing of Lightning-Conductors.
7. Suggestions for the Care and Use of Petroleum Lamps.
8. Conditions suggested to be included in Licenses for Retail Dealers in Petroleum.
9. Memorandum as to Carbide of Calcium, dated 1st March 1897.
10. Memorandum on the Electric Lighting of Factories and Magazines for Explosives.
11. Memorandum on the rendering of Magazines and Stores for Explosive structurally secure against Unlawful and Forcible Entry.
12. Inspection Form for Stores.
13. Inspection Form for Registered Premises.
14. List of Authorised Explosives (names only).