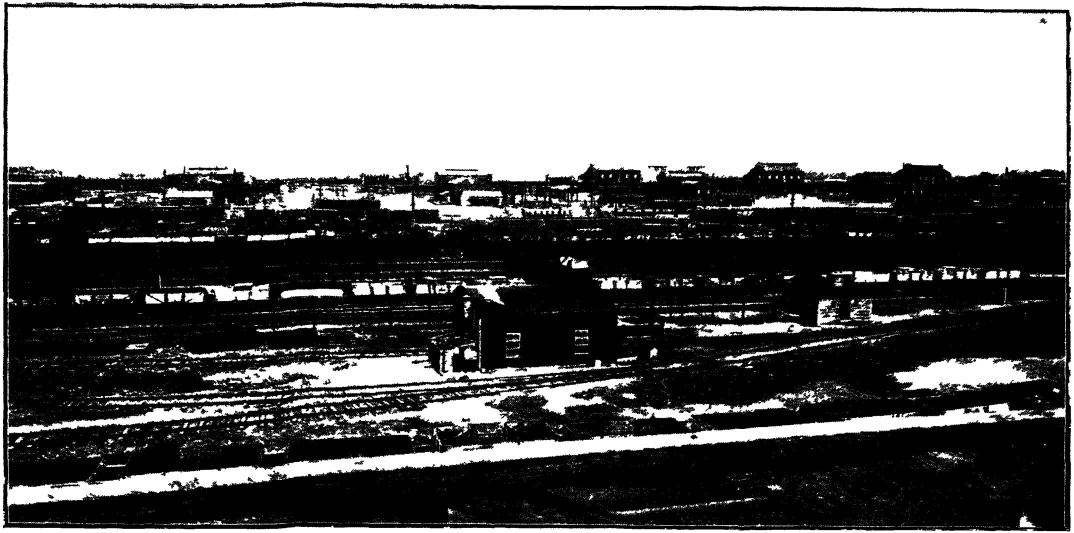
MODERN EXPLOSIVES



Frontispiece

GENERAL VIEW OF T.N.T. SITE H.M. FACTORY, QUEENSFERRY.

MODERN EXPLOSIVES

BY

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PREFACE

THE present little work has been written entirely from the experience gained by the author in the manufacture of explosives during the war. Exceptional opportunities were afforded him to gain comparative knowledge of the methods of manufacture adopted, not only in all the Allied countries, but also in Germany. More especially, he was able to go very deeply into the factors governing production, *e.g.*, efficiency, supply of raw materials, welfare and safety questions, etc. In planning the book, he has laid stress on the fundamental principles which slowly made themselves apparent as the war proceeded, of the absolute interdependence of modern industry, and of the necessity of viewing all research and productive activity as a whole, not only for defence purposes, but to safeguard social well-being, and ultimately to ensure the survival of the community.

The treatment of necessity has been very concise, but an effort has been made to give sufficient detail to bring out these fundamental principles without wearying the reader with technical data. This has involved the use of analogies and statements to which exception may be taken from the strictly scientific point of view, but the writer is hopeful that the general reader, for whom the book has been designed, will gain rather than lose thereby.

The author's grateful thanks are tendered to the late Department of Explosives Supply for the use of many photographs taken on the National Factories during the war, and to Messrs. The Asiatic Petroleum Company for the photograph reproduced in Plate No. 10.

S. I. LEVY.

SORBO,
SORBO WORKS,
WOKING,
18*th May*, 1920.

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CHAPTER I

MODERN EXPLOSIVES AND THEIR RAW MATERIALS

Though probably every thinking person has perceived the enormous suffering, misery and waste involved in modern war, and has approved the efforts made to set up means to prevent it in the future, there are few who are not attracted by and interested in its mechanism and materials, and especially the various naval and military supplies included under the term Explosives. The great war just terminated, though it has not brought about any very important discoveries in the scientific development of explosives, has considerably stimulated this interest, and the vast stocks of explosive material which its termination has left available will tend further in the same direction in consequence of the means which must be exploited to utilise them peaceably to the advantage of the community. For explosives have their uses in peace as well as in war, and though in the latter sphere their employment is the more impressive and terrible, they can be utilised no less effectively to advance the objects of industry and production.

An explosive is a substance or a mixture of substances which, under suitable conditions, can be made to suffer an extremely rapid change resulting in the production of gases and vapours occupying a very much greater space than the explosive itself. Though a great number of substances and mixtures can be made to cause explosion, the term is generally restricted to substances in the solid or liquid condition which can be made to explode as and when required. Practically any substance which will burn, or any mixture of substances which can be made to react chemically with evolution of heat, will bring about explosion if the conditions are such as to make the combustion or change sufficiently rapid and complete in an enclosed space. Conversely, many substances usually classed as explosive, and capable of causing enormous damage when made to explode in a limited and enclosed space, will burn quietly and tamely in the open air, or may even be extremely difficult to ignite at all. Thus flour, which under normal conditions can only be made to burn with difficulty, when very dry and finely divided, and distributed throughout the air of a room or building, can be caused to explode with terrible results. The explosions which may arise in coal mines from the presence of very finely divided coal dust or combustible gases are similar in origin, and are unfortunately only too well known to be capable of causing tremendous damage and loss of life. On the other hand, trinitrotoluene or T.N.T., a powerful explosive employed in enormous quantities during the war, is difficult to ignite in small lumps, and may be thrown on to a fire in small quantities without marked effect. Similarly dried guncotton, one of the most violent explosives known when compressed and detonated in a closed space, burns harmlessly when ignited in the open, and if compressed into small cakes is by no means easily ignited.

Though gunpowder, or black powder as it is now called, the first explosive made and used for military purposes, was discovered in the thirteenth century, it was not until the middle of the nineteenth century, that is, until 600 years had elapsed, that any real advance was made in the scientific study of explosives. It is curious to reflect that the Napoleonic campaigns, the most terrible in the world's history until the present century, were fought entirely with black powder, and that it is due to the advances in chemical science, advances which could and should have contributed only to the happiness, comfort and safety of man, that the war just closed has exceeded the Napoleonic wars immeasurably in ferocity and suffering and the loss of life and damage involved.

Black powder consists of a mixture of about 75 parts of saltpetre, 15 parts of charcoal and 10 parts of sulphur. Though it is no longer used as a propellant explosive, that is, for driving bullets from rifles and shells from guns, it is still manufactured on a large scale for use as a blasting explosive in quarries and mines, and for the preparation of fuses to fire blasting charges. It belongs to the class of " low " explosives, which are substances which explode by combustion, as opposed to " high " explosives, which explode by detonation. In the first class, the chemical change resulting in the explosion is started by simple ignition, and proceeds with relative slowness, the combustion spreading from one layer to the next in much the same way as in a wood or coal fire, which simply " burns through." It is obvious that under these conditions the rate of combustion depends very largely on the shape and size of the grains of powder, and the closeness with which they are packed, and by varying these factors it is possible to alter at will the speed with which the explosion proceeds, and therefore to control the pressure developed. Hence these low explosives are used entirely for propellant purposes, and for many blasting purposes where a relatively slow and regular development of pressure is required rather than a sudden shattering effect.

The high explosives, on the other hand, do not burn at all, in the ordinary sense of the word, but " detonate," and develop their full pressure almost instantaneously. This detonation, or instantaneous decomposition, is brought about by shock, and in practice is effected by the use of a detonator, which is simply a substance capable of being easily exploded or detonated by a sharp blow, and of setting up, by its own detonation, a disturbance capable of detonating the "high" explosive. For complete detonation, a high explosive must be very closely packed in its container, and strongly enclosed; if it were not, the shattering effect produced would break the container and scatter much of the explosive without detonating it. This scattering does in fact occur to some extent even when the explosive is closely packed in a shell, and the yellow smoke and discolouration of the surrounding objects characteristic of the explosion of picric acid shells is due to this incomplete detonation.

Though detonation, by comparison with combustion, appears to develop instantaneously, producing a shattering as compared with the increasing pressure effect of the low explosive, it has in fact a definite speed of propagation through the mass of the high explosive. The effect of exploding a detonator in a high explosive is to set up an "explosive wave" which travels through the latter at an enormous rate, usually about seven to eight thousand yards a second; for the purpose of the relatively small dimensions of even the biggest shells, therefore, the decomposition may be considered instantaneous.

The substance most commonly used in the preparation of detonators is fulminate of mercury, which is very easily exploded by means of a sharp blow. In consequence of its sensitiveness, its manufacture is by no means free from danger, and the most rigid precautions have to be enforced in factories in which it is made. Very small quantities only may be handled in the various operations, and each operation is conducted in a separate " house," which is mounded, or enclosed by high banks of earth, and which only the operatives employed are allowed to enter. (See Plate No. 1.) These operatives wear special clothing and shoes which are made without metal, and they are searched periodically in order to ensure that no matches, metal implements, etc., are taken into the " Danger Area." Specified distances must separate the various houses in the Danger Area, and no more than the licensed quantity of any material may be allowed to accumulate in any house or magazine. These regulations, modified to suit the particular nature of the materials produced and the operations carried out, must be observed within the Danger Area of every factory in which explosive materials are made or handled.

Explosives are most conveniently divided into classes according to the uses to which they are put. Service explosives, used for military and naval purposes, are divided into propellants and high explosives. Sporting powders are propellant powders of which the method of preparation is modified to meet special needs. The industrial and blasting powders may be either low or high explosives, according to the purpose for which they are required.

Propellant Explosives. The propellant explosives in general use have as their chief ingredients nitrocellulose or guncotton, and nitroglycerine. These two substances, as ordinarily prepared in the pure state, are among the most violent and sensitive explosives at present known, and it is very largely due to the work of Alfred Nobel, the founder of the famous firm of that name, that they have been brought under control and their great power made available with safety.

Guncotton is manufactured from cellulose, which is produced on an enormous scale in the vegetable world. All woods contain a very high proportion of cellulose, which also constitutes the fibrous part of the stems and leaves of all plants, and is found practically pure as cotton in the seed or nut of the cotton tree. The treatment of wood pulp, esparto grass, etc., in the manufacture of paper, consists essentially in freeing the cellulose from the resinous and mineral matter with which it is associated in the wood. The "ashless" filter-papers prepared for use in chemical analysis consist of cellulose almost chemically pure. For the manufacture of guncotton, cellulose is generally used in the form of cotton waste, which is the lighter fluffy material separated during the working-up of cotton for textile manufacture. This is thoroughly dried, after being picked by hand or machinery to remove foreign matter, and teased or torn up in a teasing machine in order to obtain it in a thoroughly uniform condition, free from lumps. During the later stages of the war, when, owing to the blockade, cotton was unobtainable in Germany, the nitrocellulose required for propellant purposes was made by the enemy from cellulose in the form of paper crepe prepared from wood, and by reason of their experience in the manufacture of high grade paper from wood pulp, the Germans were able to carry on the manufacture with the factories and machinery available.

After the chemical treatment described in the following chapters, guncotton is obtained as a light white fibrous material hardly distinguishable in appearance from the cotton from which it is made. It is, however, extremely different in properties, and will detonate most violently on quite small provocation, friction between metallic or rough surfaces, or a glancing

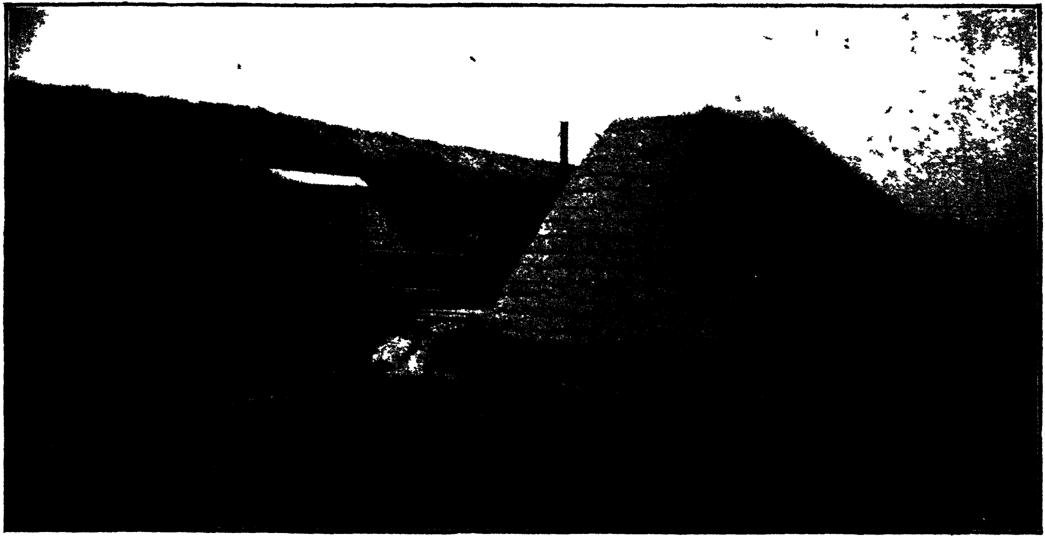

Plate No. 1

TETRYL SIFTING HOUSE, H.M. FACTORY, QUEEN'S FERRY

The house is mounded by means of sandbags, covered with a thin coating of cement.

blow, being occasionally sufficient to cause it to explode When moistened, however, it may be handled with safety, and it is generally transported and handled in this condition. Wet guncotton has the important property of being capable of explosion when detonated by means of a " primer " of dry guncotton, that is, a small quantity of dry guncotton imbedded in the compressed mass of the wet material, and ignited at will by means of a fuse. On this account wet guncotton has been largely used for the explosive charge of torpedoes; under these conditions guncotton functions as a high explosive. For propellant purposes, however, it is " gelatinised " either alone or mixed with nitroglycerine, as described in a later chapter, and worked up into the form of tape, grains, wire, or rods ; in these forms it explodes by combustion, and gives pressures controllable at will.

Nitroglycerine is seldom used alone as an explosive, on account of its great sensitiveness. It is generally used, for blasting and propellant purposes, in the form of dynamite, cordite, ballistite, blasting gelatine, etc. The raw material from which it is manufactured is glycerine, which must be prepared for this purpose in a state of great purity.

Glycerine occurs chemically combined in all animal and vegetable fats and oils, and is separated from these in the manufacture of soap. The chief oils used in the manufacture of soap are palm oil, cocoanut oil, cottonseed oil, soya-bean oil and similar vegetable oils, whilst whale oil and other liquid animal oils have recently been made available for soap and glycerine manufacture. The liquid oils are generally transformed into solid fats by a chemical process known as " Hardening," which is brought about by causing them to combine with hydrogen. The purified fat or oil is treated with caustic soda in big kettles or boilers, and the soap is " salted out " from the resulting liquid by the addition of salt. The brine solution left after the soap has been poured off is evaporated down in big multiple-effect vacuum evaporators, the salt being separated as the solution becomes denser, until a very concentrated glycerine solution is obtained. For the preparation of the pure glycerine required by the explosives manufacturer, and known as " Dynamite Glycerine," a process of vacuum distillation is employed, the glycerine solution being boiled in a vacuum and the vapours condensed in a series of separate vessels. The pure glycerine is condensed in one vessel and the more dilute mixture in others, whilst the nitrogenous impurities are left behind in the kettle, and are known as " Foots." From the foots any glycerine contained is removed by separate treatment and again distilled together with the dilute mixture obtained from the first distillation.

The preparation of pure glycerine is therefore a complicated and laborious process, and it can be readily appreciated that the problem of obtaining an adequate supply for war purposes was no light one. This problem demanded the cordial co-operation of the whole soap-manufacturing industry of the country, and was also bound up with the question of supplies of margarine, which is made from the fats and oils used by the soap-makers. In Germany it remained unsolved—the naval blockade shut off the great supplies of palm oil and other vegetable oils previously drawn by the enemy chiefly from British colonies, and led to a severe famine of fats in that country. Soap, glycerine, and margarine became almost unobtainable, and all the efforts of German chemists were unable to produce satisfactory substitutes for these essentials. It was this shortage of fats which led the Germans to adopt, among other expedients, the process of treating all animal corpses to extract such fats as could be obtained, and so aroused the rumour that the enemy was using the corpses of the killed to obtain munitions.

The Allies, thanks largely to English effort, were much more favourably placed. Soap manufacturers laid down new plant of all kinds—crushing plant to enable them to extract oil from seeds and kernels previously imported into Germany, hardening plant to enable them to deal with liquid fats previously unused, and margarine machinery on a very extensive scale. Even so, supplies would have been dangerously low, had it not been for the exploitation of the Antarctic Ocean for whales. Fisheries had been established in the southern oceans for whales just previous to the war, and the rapid expansion of these enabled us to secure enormous quantities of whale oil, from which many thousands of tons of glycerine were extracted, eventually to be made into cordite to propel shells of all calibres, laden with other explosives, from the Allied guns. The magnitude of the supplies of fats required may be gauged from the fact that to obtain 1 ton of pure glycerine requires the treatment of about 12 tons of fat or oil. Towards the end of the war, England was producing some 20,000 tons of nitroglycerine a year, requiring nearly 9,000 tons of glycerine ; this involved the treatment of considerably more than 100,000 tons of oils and fats each year for the production of this single explosive alone.

The guncotton and nitroglycerine obtained from cellulose and glycerine respectively by the methods described in subsequent chapters are subjected to various processes to bring them into the form of finished explosives ready for use. The chief of these is gelatinisation, which consists simply in bringing the explosive into the form of a jelly, hard enough to be moulded or cut, or pressed into any required shape or size, and to retain the form given to it. This process is effected by working the guncotton either alone or together with nitroglycerine, according to the character of the explosive required, into a pasty mass, with the addition of mineral jelly or vaseline, and some volatile liquid or liquids in which the guncotton is to some extent soluble, and which can be driven off again after the pasty mass, or dough as it is called at that stage, has been moulded or pressed into the desired form. A short account of the methods adopted is given in a later chapter. After the volatile liquids have been driven off again, the gelatinised explosive is blended and tested, and is then packed for despatch.

High Explosives. During the South African war, and for some years afterwards, the chief high explosive used by the Great Powers was picric acid. This was known in England as lyddite, and in France as mélinite. During the early years of the present century, picric acid was discarded on the Continent, Germany taking the lead, and trinitrotoluene was introduced in its place. The use of high explosives, until the present century, was chiefly restricted to armour-piercing shells, and to small-calibre field guns, and until the winter of 1914-15 showed that trench warfare was to be a prolonged phase of the great struggle, the British artillery considered shrapnel as the type of shell best suited to modern conditions of war. The shrapnel shell, which consists of a hollow casing filled with bullets, and containing only enough explosive to burst the case and scatter the bullets, naturally required small quantities of high explosives as compared with the shell required for use against entrenched positions, which contains as much high explosive as can be compressed into it, in order to produce the maximum shattering effect on detonation. The Germans employed their high explosive shells on a scale altogether new in war, and to put our armies on an equality with them in this respect required manufacture on a scale totally different from any of which we had previous experience.

When war broke out, though considerable quantities of trinitrotoluene had been made in Britain, lyddite was still our standard high explosive, and naturally every effort was made to increase our production of that material. At the same time, preparations were at once made to put the manufacture of T.N.T. on to the necessary scale. As the war progressed, T.N.T. was mixed more and more freely with Ammonium Nitrate, and the mixture, which was known as Amatol, became our standard high explosive. So rapidly did the introduction of ammonium nitrate progress, and so satisfactorily were the difficulties attending its use overcome, that in the later years of the war we were using the mixture known as 80/20 Amatol, which contains 80 parts of ammonium nitrate to 20 parts of T.N.T. whilst the production of picric acid was very much reduced. As ammonium nitrate is very much cheaper than T.N.T., and requires very much smaller quantities of raw materials which had to be imported, its employment in such large proportions was of great assistance to us, and very largely contributed to render possible the enormous production which enabled the artillery of the Allies to gain the mastery over the German guns which was finally achieved.

In this case also the Germans failed to keep pace with the improvements made by us under the stress of military necessity. The employment of ammonium nitrate in German high explosives remained much at the pre-war level, and never exceeded 40 per cent. of the total weight of any explosive charge, in spite of the great shortage of raw materials from which they suffered more and more as the war progressed. So much was this the case that the enemy was driven back to the manufacture of picric acid, which had to a large extent been discarded by him before the war broke out, and large works were erected in 1916-17 to make this expensive explosive, with the use of which we were able to dispense to an increasing degree as the war went on.

Picric acid is made by the process of nitration described in subsequent chapters, the starting material being Phenol, which is more commonly known as Carbolic Acid. In common with most of the organic substances used in the manufacture of high explosives, phenol is obtained from coal tar. When coal is heated in such a way that air cannot gain access to it, that is, in vessels which can be closed entirely save for one outlet, it yields four main products, gas, ammonia, tar, and coke. The tar and ammonia are obtained by cooling and washing or scrubbing the gas which is driven off, whilst the coke remains behind in the vessel, which is known as a retort. These four products of coal are of the most vital importance to industry and therefore to modern war, but the tar and ammonia are absolutely indispensible for the manufacture of explosives. From the ammonia is made, directly or indirectly, the ammonium nitrate required for amatol and similar explosives, whilst the tar yields benzene, toluene, phenol, and naphthalene, from all of which nitro-explosives are made, together with a very great number of other substances used for the manufacture of dyes, drugs and perfumes, and chemicals for photography and numerous other purposes. The tar is separated up into the various materials by processes of washing and distillation. Before the war, much more coal tar was produced in Britain than could be distilled, and very large quantities were sent to Germany for use in the German chemical industries. The Germans attached so much importance to this vital raw material that they erected plant for the distillation of coal in this country for English firms at low prices, making it a condition that the tar obtained was sent to Germany. There is little doubt that part of the toluene obtained from this country was employed for the manufacture of T.N.T. to build up the great stock accumulated for the purposes of the war. During the war the enemy experienced a considerable shortage of coal tar products for the manufacture of high explosives, and many of his factories were idle for long periods for want of these necessary raw materials.

Phenol or carbolic acid is obtained from coal tar by washing it with caustic soda, which dissolves out the phenol; after separating the solution from the rest of the tar, the phenol is obtained by adding an acid, which combines with the soda and liberates the phenol. The quantities obtained in this way were more than sufficient to supply the demand which existed before the war for this substance, for use as an antiseptic, for the manufacture of various photographic and other chemicals, and for making picric acid, which was used as a dye, and for the small quantities of high explosive required in time of peace. When the war caused such a large demand for picric acid, the supplies of this coal tar or natural phenol were soon found to be insufficient, and it became necessary to manufacture or "synthesize" phenol from benzene. Benzene is itself obtained from coal tar, of which it forms one of the chief ingredients by weight. The process of manufacture is somewhat long and troublesome, and many difficulties were experienced in erecting and working factories to make this " synthetic " phenol from benzene.

Benzene thus became an important raw material for the production of picric acid. It is also used more directly in explosives manufacture, being the starting product for making dinitrobenzene, a substance which was used on a large scale in France and Germany, chiefly in admixture with ammonium nitrate. Dinitrobenzene is an exceedingly poisonous substance, and is not one of the most powerful explosives, so it was not made on a large scale in England during the war, though plans were prepared and plant erected to make it in case of need. In France and Germany, however, where the shortage of raw materials was more acute,not only dinitrobenzene, but dinitronaphthalene, a somewhat similar body made from naphthalene, was employed.

Trinitrotoluene, which in admixture with ammonium nitrate to form amatol, has become the standard British high explosive, is made from toluene, which occurs in coal tar, though in a much smaller proportion than benzene. Both benzene and toluene are separated from coal tar, after it has been washed with various chemicals, by a process of distillation, which has to be repeated in complicated stills before the pure substances are obtained. These two substances are very similar in properties ; they are both mobile, colourless, aromatic liquids, and are classed by chemists in one family, which has a great number of members and branches, and is known as the benzene family. After benzene and toluene, the commonest members are the xylenes, of which there are three, very similar to each other, and in a lesser degree to benzene and toluene, and very difficult to separate. One of these, known as meta-xylene, was used by the French for the manufacture of an explosive known as trintroxylene, but the manufacture was troublesome and was not undertaken in England, where toluene was more plentiful.

Another substance obtained from coal tar and used in the manufacture of a high explosive is aniline. This is a heavy oily liquid, which occurs in small quantities in coal tar, from which it is generally extracted by washing with acid. It is used in very large quantities for the preparation of many of the numerous chemicals required in the manufacture of aniline dyes, and as the quantities obtained directly from coal tar are much too small to meet this demand, it is synthesized from benzene. Aniline was made in large quantities both in England and Germany before the war, and as the quantities required for the manufacture of explosives were not large, there was no shortage on either side. The explosive made from aniline rejoices in the name of trinitrophenylmethylnitramine, but it is generally known as "Tetryl." The manufacture of tetryl from aniline involves the preparation, as an intermediate body, of dimethylaniline, which is used to a considerable extent in making aniline dyes. Tetryl is very expensive to manufacture, and requires large quantities of raw materials, especially of nitric acid. It has not, therefore, been much used as a filling material for shells, but it is generally employed as a "primer," that is, as a sort of intermediary which is exploded by the detonator, and which, by its own explosion, causes the complete detonation of the main explosive used for filling the shells.

Tetryl, like trinitrotoluene, is a very stable explosive. Neither of these bodies has any action on metals, and they may therefore remain in contact with the metal parts of shells and fuses for any length of time without danger. Picric acid, on the other hand, does act on metals, forming compounds which explode very easily when struck or subjected to friction. For this reason, shells filled with picric acid are liable to become dangerous after being stored for a long time, and several fatal explosions of picric shells which have been kept for long periods have been put down to this cause. Trinitrotoluene and tetryl also have the further advantage of not being affected by water, whereas picric acid is dissolved. Trinitrotoluene also is very difficult to ignite, and is less sensitive to shock than picric acid. Picric acid has the further disadvantage from the manufacturing point of view, that it must be made practically pure for use as an explosive, whereas T.N.T. may be employed in an impure state. The manufacture of T.N.T. also requires smaller quantities of raw material than that of lyddite.

Picric acid is a bright yellow crystalline powder, with an extremely bitter taste. It dyes silk and cotton a bright yellow, but on account of its dangerous and poisonous properties, it is not much used as a dye nowadays. Trinitrotoluene, when quite pure, is a very light lemon-coloured powder, but as ordinarily prepared it is a reddish-brown crystalline substance. Tetryl is also a yellow powder. All these substances are unpleasant to handle, and turn the skin yellow. They affect the skin to a varying extent, picric acid being relatively harmless, whilst tetryl causes a severe eczema or dermatitis; trinitrotoluene is intermediate between the other two in this respect. They are all absorbed through the skin into the blood, producing more or less severe forms of poisoning, and much difficulty was experienced during the early years of the war in protecting the workpeople engaged in their preparation and manipulation. The effects, however, can be reduced to a minimum by suitable simple precautions, and the Home Office regulations now ensure practically complete protection.

CHAPTER II

THE CHEMISTRY OF EXPLOSIVES MANUFACTURE

THE nitro-explosives belong to the class of substances known to chemists as "Organic," *i.e.*, they are compounds of carbon. They are obtained by the action of nitric acid upon certain parent organic substances, generally in the presence of sulphuric acid. In order clearly to explain their nature, and the methods by which they are made, it is necessary to give a very short account of the chemistry of the operations concerned.

It is the province of natural science to study the changes which continually go on, or can be brought about, in the universe and in the matter of which the universe is built up. Physical changes constitute the province of the physicist, whilst the study of chemical change is the province of the chemist, but the two domains of science are most intimately interwoven, and in practice must be studied together. In many cases it is impossible to decide if a given change is chemical or physical, but, broadly, it may be said that in a physical change a substance does not permanently change its nature and properties, whilst in a chemical change substances taking part disappear as such, and new substances with new properties take their places. Thus the freezing of water is a physical change; the water has not changed its nature, but only its form. The same is true of sugar dissolved in water; the sugar is still present in the solution as sugar, though it is very finely divided and distributed in its divided form throughout the solution. A bar of iron heated in a fire becomes red hot, or even white hot, but it remains iron—it has suffered only a physical change. If, however, a piece of wood be placed on a fire, it burns—it disappears as wood, and new substances are formed—it has suffered a chemical change. The wood in burning has combined with some of the oxygen present in the air, and gases have been formed which have escaped by the flues: only an ash is left, which represents the mineral substances originally present in the wood. If the wood has not burned completely, a black mass is left—this consists of the mineral substances together with some of the carbon of which the wood was composed, which has not combined with oxygen and escaped as gas.

The carbon and the ash formed from the wood represent substances which were originally present in the wood Wood is in fact a mixture of many substances, not a single substance, though it consists largely of one single substance, cellulose, which is extracted from it in a fairly pure state in the manufacture of paper from wood pulp. The best grades of filter paper, for example, are almost pure cellulose, and dry cotton-wool is also nearly pure cellulose. If filter paper or cotton-wool be thrown on a fire, it will burn. If it is allowed to burn completely, there is no visible residue—the products are all gases which escape undetected. If, however, the combustion is not complete, a black mass is again left—this black mass consists largely of carbon, which must therefore be present in some form in the cellulose. Cellulose then is a pure substance which in some way contains or consists of another substance carbon.

If a quantity of dry cellulose be weighed, and strongly heated in a vessel arranged so that no air comes in contact with it, only carbon will be left; if the vessel be cooled and the carbon weighed, it will be found to weigh less than the original cellulose. If the vessel be again strongly heated, but this time in presence of air or oxygen, the carbon gradually disappears—it is transformed into a gas, carbon dioxide, which can be collected and weighed. This gas weighs more than the carbon from which it was formed, and is said to be a compound of carbon and oxygen. If the gases formed in the complete combustion of cellulose be collected and examined, they will be found to consist only of carbon dioxide and water vapour or steam. Water vapour is known to be a compound of oxygen with hydrogen; it follows, therefore, that the cellulose must contain hydrogen in addition to carbon, and it may also contain oxygen. It can in fact be proved to contain oxygen, by showing, as chemists have shown, that the oxygen used up when cellulose burns is less than the amount of oxygen required to produce the amounts of carbon dioxide and water vapour formed, the difference corresponding exactly with the oxygen present in the cellulose itself.

An explosive has already been defined (Chapter I) as a substance or mixture of substances which can be made to undergo very rapid chemical change, with the production of substances, mostly gaseous, which occupy a very much greater space than the explosive itself. The chemical change which most explosives undergo is in the nature of combustion, or burning with oxygen, and therefore oxygen is present in large quantities in most explosives. Cellulose itself, as explained above, contains oxygen, but not in sufficient quantity to make it an explosive. Oxygen can be supplied in the necessary quantity, however, either by mixing with the cellulose other substances much richer in oxygen, or by causing the cellulose to suffer a chemical change by which the amount of oxygen it contains is increased to the desired amount. The second method of effecting this is the foundation on which the manufacture of most modern explosives is based; it consists in the "Nitration" of cellulose, that is, the treatment of cellulose with nitric acid, which produces nitrocellulose, or guncotton, a derivative so rich in oxygen that when it is detonated all the carbon and hydrogen originally present in the cellulose form gases by combination with this oxygen, and so produce the tremendous pressures which give guncotton its value as a propellant explosive.

Since nitrocellulose contains more oxygen than cellulose, it is evident that this must come from the nitric acid which is used in its manufacture. Nitric acid is in fact very rich in oxygen, which constitutes more than 76 per cent. by weight of the acid, and this fact explains the great importance of nitric acid and its compounds in the preparation of explosives.

Nitric acid is a compound of hydrogen, nitrogen and oxygen. Until the twentieth century, the only practical source of the acid and its derivatives was saltpetre, of which two varieties are known. Ordinary saltpetre, known chemically as potassium nitrate, has long been obtained in the East from "plantations" in which animal and human excreta produce the compound as a result of chemical change. Chili saltpetre, or sodium nitrate, occurs in enormous deposits in the desert regions near the Pacific coast of Chili, and has been formed by the accumulation, during vast periods of time, of the dried guano of birds. These two saltpetres are soluble in water and therefore are found only in waterless and desert regions. They are known chemically as "Salts" of nitric acid, and can be obtained by neutralising nitric acid with the alkalies potash and soda respectively. If the alkali ammonia be used to neutralise the acid, the important salt ammonium nitrate is produced. The salts of nitric acid are frequently used for making up explosive mixtures on account of the high proportions of oxygen they contain, and ammonium nitrate, which is especially suitable, was used at the rate of several thousands of tons a week by the Allies for this purpose during the war.

The raw materials for the manufacture of the nitro-explosives have been dealt with in the previous chapter. They are, for propellant explosives, cellulose and glycerine, and for high explosives, benzene, toluene, naphthalene, phenol, dimethylaniline, xylene, and to a smaller extent other similar substances. All these bodies are " Organic," that is, they are compounds of carbon; all of them also contain hydrogen, and cellulose, phenol, and glycerine contains also oxygen. Carbon, hydrogen, and oxygen are known as " Elements." They are substances which the chemist deems to be simple, and which he is unable to " analyse " or split up into other substances. The elements combine among themselves to form " Compounds," which are bodies which the chemist is able to analyse into simpler bodies or elements, and which he can frequently build up or " synthesise " again from those elements. The chief constituents of the air, nitrogen and oxygen, are both elements, as is also hydrogen, which is the chief constituent of the atmosphere of the sun and most of the stars. Hydrogen and oxygen combine to form water, as can be shown both analytically and synthetically; if an electric current be passed through water, hydrogen and oxygen are formed, whereas if hydrogen is burnt in oxygen, water is produced. Hydrogen, oxygen and nitrogen combine to form nitric acid, which is therefore a compound of these three elements.

The treatment of the raw materials of the explosives mentioned above with nitric acid is known as nitration. As a result of this treatment, hydrogen is removed both from the organic material and the nitric acid, together with a small proportion of the oxygen, the two elements forming water, which is produced in every nitration, whilst the nitrogen and the rest of the oxygen from the nitric acid combine with the rest of the organic material, forming a "nitro-compound" which in these cases constitutes the explosive. The chemical names of the explosives generally consist of the name of the raw material, in front of which is placed the disyllable "nitro," and generally a prefix, di-, tri-, tetra-, etc., is added which shows the relative amounts of nitrogen and oxygen which have been introduced into the original organic material by the process of nitration.

Nitration of organic bodies can generally be carried out simply by mixing these with nitric acid, but the operation is dangerous and may result in explosion, since the nitration under these conditions proceeds too rapidly to be easily controlled, and the heat which is always liberated cannot be removed quickly enough. The process is therefore always carried out on the large scale in the presence of sulphuric acid, which serves the double purpose of taking up the water formed, and of causing the nitration to proceed smoothly and quietly. Sulphuric acid is a compound made up from the elements hydrogen, oxygen, and sulphur. It is known generally as "Vitriol," a contraction of "Oil of Vitriol," a name given to it by the early chemists, who first obtained it by heating green vitriol, which is the iron salt of sulphuric acid. Green vitriol is a crystalline substance occasionally found in nature; when strongly heated, it yields sulphuric acid, which distils off and may be condensed, leaving behind very finely divided red oxide of iron, which is the rouge of the jewellers' *workroom and the dressing table.*

Since *both nitric and sulphuric acids are required for* the manufacture of explosives, all explosives factories must be equipped to deal with them; all the factories erected during the war were provided with plant to make their own nitric acid, and many were equipped with plant to make their own sulphuric acid. The latter is not changed chemically in the nitration, but is recovered after the process; since, however, it takes up the water formed, it is generally not suitable for further use, but must be concentrated or freed from this water, an operation effected by heating it sufficiently to make the water boil off. Before the war, and to some extent during the war, the sulphuric acid left after nitration, termed "waste" or "spent" acid, was often thrown away or sold, but most factories erected during the war in Britain were provided with concentrating plant to make the acid strong enough for further use. Since sulphuric acid is made almost entirely from imported sulphur and ores containing sulphur, it became vital in England to make its use as economical as possible.

Nitric acid has always been made in England by the action of sulphuric acid on nitrate of soda, or Chili saltpetre. This substance is found in very large quantities in the deserts of South America, between the Andes and the Pacific Ocean, where it has been formed by the accumulation during vast periods of time of guano, the dried droppings of birds. It is separated from the sand and earth with which it is admixed by treatment with boiling water, which dissolves it, and from which it is again deposited, after the separation of the insoluble sand and earth, by evaporation and cooling. Many hundreds of thousands of tons are obtained annually, and exported to Europe and the United States, for it is much used as a fertilizer. During the war, most of the available supply was required for the manufacture of nitric acid for explosives, and the British Government very early took over the purchase and distribution. As the other great nitrogenous fertilizer, ammonium sulphate, was also required for the manufacture of explosives, agriculture during the war suffered considerably from the shortage of these essential materials.

Nitrate of soda, or to give it its correct name, sodium nitrate, is a " salt " of nitric acid, that is, it is a compound of nitric acid in which the hydrogen of that substance is replaced by the metal sodium. It is a property of salts that the acid from which they are formed can be displaced or driven out by a stronger acid. The commonest and cheapest acid used by the chemical industry is sulphuric acid, and this is generally used when it is required to displace other acids from their salts. When sulphuric acid is heated with nitrate of soda, the nitric acid displaced from the latter is boiled off, and may be condensed and collected, whilst salts of sulphuric acid with the sodium remain behind in the reaction vessel. In this manner practically the whole of the enormous amounts of nitric acid used in Britain for the manufacture of explosives was prepared. The residue from the process, known as nitre-cake, and consisting of salts of sulphuric acid with sodium, is still acid in character, and its disposal during the early years of the war was a troublesome matter. As the supplies of sulphuric acid were diverted more and more from the normal commercial uses to the manufacture of explosives, this acidic nitre-cake was suggested for use in its place by the Government, and large quantities were consumed for various purposes during the later years of the war.

Although before the war Britain produced a very large amount of sulphuric acid, chiefly for the manufacture of washing soda, superphosphate and ammonium sulphate, the great quantities required for explosives could only be obtained, having regard to the industrial requirements of the country, by the erection of new factories, and most of the larger explosives works constructed during the war were equipped with plant for this purpose. Sulphuric acid is manufactured by burning sulphur, or some mineral containing sulphur, in air. When this is done in the ordinary way, a suffocating gas called sulphur dioxide, which is a compound formed from the elements sulphur and oxygen, is formed. This fact is used when it is required to fumigate or disinfect dwellings and articles which have been exposed to infection; the rooms are sealed up, and sulphur is ignited in them, the sulphur dioxide produced penetrating everything in the room in which it is formed, and destroying all insects and bacteria. This gas can, in the presence of certain other substances, combine again with oxygen, forming a compound known as sulphur trioxide; this latter oxide unites most eagerly with water, forming sulphuric acid.

Two classes of substances are generally used to cause the combination of the sulphur dioxide with oxygen. The first are compounds of oxygen and nitrogen, conveniently known as nitrous fumes, and the method generally employed for making sulphuric acid on a large scale consists in passing the sulphur dioxide, mixed with oxygen and nitrogen from the air, together with these nitrous fumes and water vapour, into large leaden chambers, on the floors of which the sulphuric acid formed collects. This process, known as the "Chamber Process," gives sulphuric acid mixed with about one-half of its own weight of water, a mixture very suitable for the manufacture of superphosphate and ammonium sulphate. For the manufacture of explosives, however, a stronger sulphuric acid is required, and chamber acid had therefore to be concentrated for this purpose to a strength corresponding to 5 or 6 per cent. of water only. This strong acid is known commercially as R.O.V. (Rectified Oil of Vitriol), or C.O.V. (Concentrated Oil of Vitriol).

The second class of substances used to assist the combination of sulphur dioxide and oxygen consists of certain finely divided metals, of which platinum gives the best results. The methods in which platinum is used for this purpose are called " Contact Processes " to distinguish them from the chamber process, the name indicating that the platinum appears to act by contact alone, and not by chemical reactions, as the nitrous fumes used in the chamber process appear to do. The advantage of the contact processes is that the presence of water is not necessary—it is, indeed, harmful—so that the sulphur trioxide formed can be caused to combine with any quantity of water desired, and so acid of any strength obtained without the need for concentration.

During the war, Germany and Austria were completely cut off from supplies of Chili saltpetre for the manufacture of nitric acid, and but for the skill of the German chemists and engineers, the enemy must have been beaten from lack of nitric acid to make explosives some years before the war was actually brought to a conclusion. The Germans succeeded, however, in synthesizing nitric acid from its elements, hydrogen, oxygen and nitrogen, and were able to make not only nitric acid for explosives but nitrates for fertilizers by this means.

The manufacture of nitric acid without the use of sodium nitrate can be carried out in many ways. The process in fact occurs in nature during thunder-storms; by the action of lightning the nitrogen and oxygen of the air combine, and in presence of moisture form nitric acid. This natural process has been imitated on a large scale in Scandinavia, where electricity, generated by utilizing the power of the waterfalls of the country, is employed to cause union of nitrogen and oxygen in the same way as the lightning does. The electric current is made to form great arcs many feet in length, which are caused to rotate and move in various ways by the action of magnetic fields. Air is forced rapidly through these "flaming arcs" and the nitrous gases formed are absorbed by water in enormous granite towers, with formation of dilute nitric acid.

This direct or arc method of making nitric acid is, however, expensive, and especially cannot be employed unless large quantities of electric energy are available. Of the other methods which have been proposed and brought into use during the present century, the most promising is that which was adopted in Germany and by means of which many hundreds of thousands of tons of nitric acid were manufactured during the war. This process rests upon the fact, discovered by the German chemist Ostwald, that ammonia in presence of finely divided platinum, will burn to yield oxides of nitrogen, which, in the presence of air and moisture, can be converted into nitric acid. The preparation of ammonia from its elements nitrogen and hydrogen was satisfactorily accomplished by the German chemist Haber, and shortly before the war the Badische Anilin und Soda Fabrik brought into operation the first commercial synthetic nitric acid plant using the Haber-Ostwald process. It is generally believed that the German government financed the process, and it is quite certain that without its successful operation Germany would have been unable to continue the struggle.

The manufacture of ammonia from nitrogen and hydrogen requires extensive and complicated plant. In the first place, pure nitrogen must be obtained. This is effected by liquefying air and allowing it to boil again in such a way that the nitrogen, which boils more easily than the oxygen, can be boiled off first and obtained pure. The hydrogen is prepared from water gas, which is a mixture of hydrogen and carbon monoxide obtained by passing steam through glowing coke. The hydrogen is purified from the carbon monoxide by a long process, most of the details of which are very jealously guarded by the Badische firm. These two gases, after the most exhaustive purification, are passed into "bombs," which are steel cylindrical vessels in which the gases, at a high temperature and under enormous pressure, are brought into contact with substances which cause them to combine to a very small extent, yielding ammonia This ammonia is then washed out of the gases, which go back again to the bombs whilst the ammonia is dried and goes on to the burners in which it forms the oxides of nitrogen. So intricate are the engineering appliances required, and so enormous are the pressures under which the Haber reaction is carried out, that it is safe to say that only the advances in metallurgy of the last few years could have rendered it possible to carry out the process at all.

The nitric and sulphuric acids obtained by the processes outlined above must now be blended, according to their strengths and to the particular explosive to be prepared, to form a "Mixed Acid" for nitration. The organic raw material to be nitrated is now brought into contact with the mixed acid in an apparatus which can be cooled or heated as required, when nitration occurs. After the reaction, the nitrated material is separated from the spent acid, washed free from acid and subjected to the finishing operations necessary to bring it into the form in which it is to be used. The spent acid, which consists of sulphuric acid diluted by the water formed in the reaction, together with larger or smaller quantities of nitric acid and of the nitro-compounds formed, is freed from the latter by appropriate means, and is then either reinforced with strong sulphuric acid and fresh nitric acid if the nature of the nitrating reaction allows, or subjected to " Denitration," which is an operation by which the nitric acid it contains is removed and recovered from subsequent use. The denitrated spent acid is then treated in concentrators to drive off the water formed in the nitration, and is ready for further use.

It will be seen, therefore, that the manufacture of explosives involves to a large extent the manufacture and handling of nitric and sulphuric acids. As these are highly corrosive and dangerous liquids, stringent precautions have to be adopted on all factories, quite apart from the care which must be taken in handling the explosive materials themselves. The acid sections of the modern factory are described in the following chapter, and in the succeeding chapters the nitration and finishing sections are dealt with.

CHAPTER III

THE ACIDS SECTION OF AN EXPLOSIVES FACTORY

THE acid side of an explosives factory usually constitutes a more or less separate and self-contained section, situated outside the Danger Area. In a typical modern factory, the acid side would contain the following sections: (1) Nitric Acid Plant; (2) Sulphuric Acid Plant; (3) Acid Mixing and Storage Plant; (4) Waste Acid Receiving and Storage plant; (5) Denitration Plant; and (6) Concentration Plant. The first three sections are concerned with the manufacture of the fresh mixed acid for use in the nitration plant in the danger area; the last three sections are concerned with the treatment of the waste acid received from the nitration plant and the preparation from it of fresh nitric and sulphuric acids for further use or for disposal.

The acid side of the factory will generally be under the control of a separate manager who acts in co-operation with the manager of the other side of the factory, the explosives plant proper. In this chapter a short account will be given of the operation of each of the six sections of the acid side.

SECTION 1

Nitric Acid Plant. Up to the present, nitric acid has always been made in this country by the action of sulphuric acid on nitrate of soda. For making the strong nitric acid generally required, it is necessary to have both these materials as free as possible from water. Chili saltpetre readily takes up moisture from the air and it is usual to dry it before use. This is effected by causing it to travel slowly through a closed iron vessel, through which the hot gases from a coke fire are conducted. The sulphuric acid used generally contains about 6 per cent. of water; it is customary to use the acid obtained from the concentration plant for this purpose. The vessel used for the reaction is made of cast iron and is cylindrical in shape, with a rounded bottom. This vessel, known as a Retort, will generally be about 7 ft. in diameter and 7 to 8 ft. deep, and will take a charge of 2 tons of dried nitrate and about 2 tons of concentrated sulphuric acid. The cast iron cover is provided with a manhole for the introduction of the nitrate, and a central opening for the escape of the nitric acid vapour. In the bottom is an exit, which can be closed at will, for the escape of the liquid nitre-cake after the reaction is finished. The retort is built into brickwork flues, so that it can be heated by means of a coal or gas fire.

The nitric acid, which escapes in the form of vapour when the charge is heated, is extremely corrosive, and the pipes for conveying and condensing it could until recently only be made of earthenware. During the last few years plant made from silica or fused quartz has been introduced, and is now employed with great success. Various alloys of iron with the element silicon, known as Acid-proof Iron, have also been introduced under the names Tantiron, Narki Metal, Duriron, Ironac, etc., and these are used not only for making pipes of various kinds, but also for pumps, valves, and even tanks. The nitric acid vapour is led through pipes of one of these materials to condensers of various forms, cooled on the outside by means of water. In these condensers the acid vapour assumes the liquid form, and is collected in tanks placed beneath. (See Plate No. 2.) Small quantities of uncondensed vapour, and of fumes formed by decomposition of the

Plate No. 2

NITRIC ACID RETORT HOUSE, H.M. FACTORY, GRETNA

Testing Condensed Nitric Acid, collected in earthenware receivers to trioxide is first carried out in a "Converter," and the gases then pass to " Absorbers," in which the trioxide is absorbed in weak sulphuric acid, which serves to carry the water required for the combination. The reaction of sulphur trioxide with water is so violent that it cannot safely be carried out directly; the water, therefore, is presented in the form of dilute sulphuric acid, and under these conditions the reaction occurs quietly. If just sufficient water is supplied exactly to combine with the trioxide made, pure sulphuric acid is formed; if insufficient water is present, part of the trioxide combines to form sulphuric acid, and the remainder dissolves in the acid formed. This solution or mixture of sulphur trioxide and sulphuric acid is known as " Oleum " or Fuming Sulphuric Acid; it is this material which is required to a large extent in explosives manufacture, and the shortage of which was much felt in the early years of the war.

The reason of the contact process, as first attempted in this country, proving unsatisfactory, was that the necessity for purifying the gases coming from the burners was not understood. Unless all traces of moisture, arsenic and other substances are removed, the platinum which brings about the oxidation to the trioxide becomes " poisoned " and after a time is quite ineffective. Why this should be so is not known, and the fact itself was not known to the earlier workers. Since platinum is very expensive, the cost of providing new metal to keep the process going became extremely heavy and it was abandoned. It is now known that even if the platinum becomes poisoned, it can be restored again, but the process is troublesome. The poisoning is in consequence a great source of trouble and delay, and stringent precautions must be taken to avoid it if a contact plant is to be worked successfully. For this reason expert and experienced supervision is necessary on plants of this type. Chamber plants, on the other hand, can be run successfully with a minimum of supervision, and this may have been one of the reasons why contact plant was not introduced on a larger scale in England once the chamber process had become well established.

All plants for the manufacture of sulphuric acid are continuous, that is to say, raw material is constantly fed into the burners, and the finished product is drawn off in a continuous stream. Nitric acid retorts, on the other hand, are generally discontinuous: the charge is put in, the nitric acid boiled off, and the nitre cake removed; the retort is then ready for a fresh charge, which can be made at once, or after an interval of time, as may be found most convenient. A sulphuric acid plant, however, takes days to reach the proper conditions for efficient production, and cannot be shut down quickly. Much chemical plant is of this description, and many processes can only be carried out continuously, so that night work, week-end work, and even holiday work must be the rule if efficient production is to be kept up.

SECTION 3

Acid Blending. The function of the acid blending or mixing plant is to supply to the nitration section a mixed acid of exactly the composition required for the manufacture of the particular explosive to be produced. All nitration acids contain pure nitric and pure sulphuric acids in varying proportions, together with greater or smaller quantities of water. Three acids are available for mixing—oleum, sulphuric, and nitric. The first will generally be of definite composition, containing usually 80 parts of pure sulphuric acid and 20 parts sulphur trioxide. The function of the latter is to combine with the water which will generally be present in the nitric and sulphuric acids available for mixing, which it does with the formation of more pure sulphuric acid.

Before mixing can commence, the exact strength of each acid to be used must be determined by analysis; when this is known, the amounts of each to be used to produce a mixed acid of any definite composition required can be calculated. The actual operation is generally carried out in steel or lead-lined vessels fitted with mechanical stirring devices, and coils through which cold water can be circulated to remove the heat which is generally liberated.

Blending operations can be varied within wide limits by modifying the strengths of the acids used. The blending plant should be regarded as the centre of the acid factory, and by its requirements all other operations on the acid side should be regulated. Failures to view the acid plant as a whole, centred about the blending plant, may lead to much waste of labour and materials, since in the acid factory opposing operations are always going on, which should be balanced to secure best results. Thus, in the contact plant water is continually being added to combine with the sulphur trioxide, whilst in the concentration plant water is being boiled off from the weak sulphuric acid returned from the nitration department. For the national factories the most detailed balance sheets were drawn up to ensure that waste of labour and fuel was eliminated, and all the complicated factors involved were reduced to the simplest basis by means of exhaustive tables and diagrams.

SECTION 4

Waste Acid Plant. The mixed acid prepared by the blending plant is pumped or otherwise transported to the nitration plant, described in the next chapter; after the nitration, the waste acid left is separated from the nitro-body formed, and pumped back to the acid site. The separation from the nitro-body is generally not entirely complete, and precautions must be taken to avoid danger in handling the acid. Nitro-glycerine and T.N.T. spent acids nearly always contain small proportions of these explosives. The spent acid is allowed to remain at rest for as long as possible in big lead-lined or steel tanks, and the nitro-body which rises to the surface is skimmed off at intervals.

In the nitration of cellulose to form gun-cotton, a very great weight of acid is used compared with the quantity of cellulose. The waste acid therefore does not differ very much in composition from the fresh acid used, only a small proportion of its nitric acid having been used up and a small proportion of water added. It is therefore possible to restore the spent acid to the composition of the fresh acid by adding to it a " Revivifying " acid, which is made up from very strong sulphuric and nitric acids. The waste acid from the nitro-cellulose nitration is therefore divided into two fractions, the larger quantity being revivified for the next nitration, whilst the smaller fraction is treated for the recovery of strong nitric and sulphuric acids as described below.

SECTION 5

Denitration Plant. There are two types of plant for recovering nitric acid left in the spent acids after nitration. In the manufacture of guncotton, the spent acid obtained contains only nitric and sulphuric acids and water, and the nitric acid is readily driven off from this by boiling, since it is much more volatile than the sulphuric acid, which retains most of the water. The vessels in which this operation is carried out are known as stills, since they serve to distill the nitric acid. They are simply very big cast-iron pots, in shape and size very similar to the nitric acid retorts, and are provided at the top with inlets for the waste acid and outlet pipes for the nitric acid vapours, which are led to condensers and receivers exactly in the same way as in the case of the retorts. After the nitric acid has been distilled off, the sulphuric acid remaining is generally discharged by means of compressed air through a pipe reaching down to the bottom of the still and passing out through the top. This method of emptying the stills is generally adopted in preference to running the acid off from the bottom, since the corrosive nature of the hot acid renders it very difficult to keep tight the valve or cock which would be required.

In some cases the distillation of the nitric acid is made continuous by means of what is known as a "Column Still." This consists simply of a vertical cylindrical vessel which can be heated from the outside; the spent acid is allowed to flow in continuously from the top, the nitric acid distils off as the liquid descends through the hot vessel, and the sulphuric acid, free from nitric acid, runs out continuously from the bottom into cooling vessels. The nitric acid vapour escapes continuously from the top of the vessel, and is led to condensers as before.

In the nitration of T.N.T., nitro-glycerine, picric acid, and other explosives, a waste acid is produced which contains besides nitric and sulphuric acids various other compounds of nitrogen formed from nitric acid by the removal of a part of its oxygen by the organic matter. These compounds can be decomposed by water, forming nitrous fumes, which can be converted again into nitric acid. Such waste acids cannot be completely denitrated in stills, and are therefore treated with steam in vertical columns. The action of the steam is to decompose the nitrogen compounds, liberating nitrous fumes which are drawn away to " Absorption Towers," in which they are converted to nitric acid. This conversion is effected in the presence of water by means of oxygen, to supply which air is drawn in to the towers with the nitrous fumes. On account of the corrosive nature of the weak nitric acid produced, the towers are built of earthenware, and are filled with packings of various kinds, which will withstand the action of the acid. The water necessary is circulated through the towers by means of glass pipes. Since nitrous fumes are produced in practically every operation involving the manufacture of handling of nitric acid and explosives, these absorption towers are a very common and necessary feature of the factory, not only because nitric acid is far too valuable to be lost or wasted in any way, but also because the fumes are extremely corrosive and poisonous.

SECTION 6

Sulphuric Acid Concentration Plant. The sulphuric acid obtained from the denitration plant is diluted with all the water which has been formed or added during the operations of nitration and denitration, and before it can be used again on the factory this must be removed. Concentration is effected by taking advantage of the fact that water boils at a much lower temperature than sulphuric acid, though the attraction which exists between these two substances makes the removal of the water more and more difficult as the acid becomes stronger. On account of the corrosive nature of hot sulphuric acid, much difficulty was encountered by the earlier workers in finding materials which would withstand its action. Glass vessels were at one time used but their liability to breakage and the risk of very serious accidents which this involved made them too dangerous. Platinum vessels and iron vessels lined with platinum were also employed, but the cost of these was prohibitive. The improvements of the last twenty years have, however, provided more suitable materials, and many types of concentration plant are now in use which can be erected cheaply and worked with ease and safety. All these modern plants operate continuously, that is, the dilute acid is run in continuously at the top, whilst the hot concentrated acid flows off in a steady stream at the bottom.

The types of plant most generally in use when the quantities to be handled are not very large, are known as "Cascades" and "Kesslers" respectively. The cascade plant consists of a series of small vessels arranged like the steps of a staircase so that the acid flows downwards from one to another. The vessels are arranged to sit in suitable apertures on the top of a flue. Beneath the bottom trays a fire is kept going, and the hot gases from this ascend the flue, heating the acid in each vessel as they pass up. By this arrangement, the acid is more and more strongly heated as it flows through the cascade, and becomes more and more concentrated as it passes from the upper to the lower vessels. The upper trays are not covered in, as practically only water is driven off from them, but the water vapour driven off as the acid becomes more concentrated carries with it increasing quantities of acid, and the lower part of the cascade is therefore covered in, in order that the fumes may be collected instead of escaping into the air. From the covered-in part the fumes are drawn away through leaden vessels filled with coke, called Scrubbers, in which much of the sulphuric acid vapour is condensed. The vessels forming the cascade are generally made of silica or quartz, which is moulded in the electric furnace, or of one of the acid-proof iron-silicon alloys already mentioned.

The Kessler plant consists of a series of lead plateaux, or trays, arranged one above the other. The acid flows down these and then into a big iron vessel which is placed above a grate or fire-bed. The hot gases from the fire are made to bubble through the acid in each of the lead trays in succession by means of a sort of mushroom arrangement in the bottom of each tray. This type of apparatus is more compact than the cascade, but is more difficult to work continuously for long periods as it is liable to become choked by the sediment already present in the acid and formed by corrosion of the lead.

For dealing with larger quantities of acid, big towers are employed. The acid is pumped into the top of these through spray devices and falls down the tower in the form of a very fine mist or spray. Furnaces are built at the bottom of the towers, and the gases from these passing upwards heat the fine drops of acid and cause very rapid and effective concentration. The gases escape from the top of the tower, carrying with them the water vapour and acid fumes, and are led to scrubbers. Recently many new types of scrubber have been introduced to replace or supplement the leaden vessels filled with coke generally employed, since these are very cumbrous and relatively inefficient. It has been found, for example, that if the gases are made to pass very quickly through a very narrow orifice most of the sulphuric acid vapour is condensed. A device which was first tried during the war in England is the "Electrostatic Precipitator," in which the gases are caused to pass between electrodes charged to a potential of

20,000 volts. The effect is to attract the mist of sulphuric acid particles to the leaden plates forming one of the electrodes, on which the fumes condense to dilute sulphuric acid. The dilute acid from these scrubbing devices is collected and returned to the concentrator.

CHAPTER IV

THE MANUFACTURE OF PROPELLANT EXPLOSIVES

FROM the time of the introduction of explosives until after the Franco-Prussian war, the only explosive in use for all purposes was gunpowder. In this early period, the explosive was used for military purposes almost entirely as a propellant, that is, as the agent by means of which the projectile was forced from the weapon used. As the use of artillery increased, and guns and projectiles alike grew in size and weight, it was found desirable to employ some explosive which would develop its power under conditions more easily controlled. In consequence of this need, black powder was somewhat modified, and a variety called "Brown" or "Cocoa" powder was employed. In this form, somewhat different proportions of nitre and sulphur were used, and the charcoal was replaced by wood less completely charred. This powder contained also varying amounts of moisture, and was made up into masses of various sizes and shapes, the object being by these means to obtain slower combustion and consequently slower and more regular development of pressure in the barrel of the gun. The barrel was also lengthened, so that the pressure might be developed during the actual time the shot was travelling along the gun, obtaining its maximum at the moment the shot reached the end of the barrel.

During the years following the Franco-Prussian war, high explosives were introduced and gunpowder was replaced for propellant purposes by the present nitro-cellulose and nitro-glycerine powders. By the time of the Russo-Japanese war, this change was practically complete, and in that as in the recent war, modern explosives were used on these lines. The propellant chiefly employed was Cordite, which is made from nitro-cellulose and nitro-glycerine. Whilst the latter of these is a definite chemical substance, of constant composition and properties, nitro-cellulose is a mixture of substances, the composition and properties of which vary according to the method of preparation.

In the nitration of cellulose, the amount of nitrogen and oxygen introduced depends upon the composition of the mixed acids used, the time occupied in the nitration, the temperature, and other factors. In consequence, the product is usually designated by the percentage of nitrogen which it contains. The most highly nitrated cellulose contains between 13·2 and 13·3 per cent. of nitrogen; this was the substance originally used for the manufacture of cordite, under the name of gun-cotton. It is dissolved by acetone, but is insoluble in alcohol and mixtures of alcohol and ether. A less highly nitrated product containing 12·4 per cent. of nitrogen is, on the other hand, soluble in alcohol-ether mixtures. This variety, together with other kinds of nitro-cellulose containing lower percentages of nitrogen, has found a great number of industrial applications under the name of collodion, which is the chief ingredient of the earlier kinds of celluloid. Owing to its inflammable nature, however, many efforts have been made to replace collodion by other materials, and various non-inflammable celluloids for the manufacture of cinematograph films are now in use. Collodion also found an important application in the manufacture of artificial silk. Ordinary cotton consists of threads which are built up from a large number of very short fibres twisted together. Silk, on the other hand, is composed of fibres of very great length and owes its characteristic lustre to this fact. This lustre is imitated in artificial silk by getting the cellulose of which cotton is composed into the form of continuous threads. Nitrocellulose is dissolved in a mixture of alcohol and ether and the solution is forced through very tiny jets into a chamber sufficiently hot to drive off the alcohol and ether and leave the cellulose in the form of a continuous thread, which is then wound on spindles. This continuous thread, when woven into fabrics, gives to these a lustre equal to that of natural silk, but such fabrics have not the strength of real silk, and are very easily torn. On account of the inflammable nature of the nitro-cellulose, such fabrics are usually chemically treated so to modify the collodion as to render it safe for ordinary purposes.

The different solubilities of nitro-cellulose containing 12·4 per cent. of nitrogen and of guncotton containing 13·2 per cent. of nitrogen, became of great importance for the manufacture of cordite in this country. The process, as originally patented by Nobel, specified the use of a soluble cellulose. When manufacture for military purposes was undertaken by the Government, guncotton containing 13·2 per cent. of nitrogen was used and when Nobels brought an action against the Government for infringement of patent, it was contended that the use of this material, which is insoluble in the solvent employed by Nobels, constituted an alteration in process, and this contention was upheld by the Court.

Preparation of Nitro-cellulose. Whatever the composition of the nitro-cellulose required, the process of nitration and the subsequent operations remain the same. The cotton must first be prepared for nitration by removing from it all moisture and foreign matter. For this purpose, it is first passed through drying machines, in which the moisture is carried away by a current of warm air. The dried cotton is then passed through a number of machines which tease and pick it, separating from it the fragments of metal, wood and other foreign substances present, breaking up all lumps, removing all dust, and finally delivering it in a pure condition suitable for nitration. In many cases machine picking is not considered sufficiently reliable, and hand picking is resorted to. For most purposes the ordinary cotton waste of the textile industry is used, but occasionally the very highest grades of cotton are employed. On large factories the cotton is moved from one machine to another, and from the preparing to the nitrating department by means of compressed air operating through very wide enclosed metal channels.

It has been suggested that cellulose in the form of wood pulp might be used for explosives manufacture, and there is reason to believe that this was actually done in Germany during the war. In the form of paper made from wood pulp, cellulose is easily nitrated, and there is the advantage here that the tedious preparation required in the case of cotton waste is not necessary. Attempts have also been made to prepare explosives from starch, which chemically is related to cellulose, but so far the nitro-starch explosives have not met with any degree of success.

The dry clean cotton from the preparation department must be treated with mixed acid without loss of time, as it very readily takes up moisture from the air. The nitration is carried out in big earthenware vessels, from 4 to 6 ft. in diameter and about 18 ins. deep. These vessels are provided with perforated false bottoms upon which the cotton rests. A charge of cotton is from 20 to 30 lbs., and for full immersion this requires about thirty times its own weight of mixed acid. After the cotton has been immersed in the acid, a perforated plate is placed over it, and a thin film of water is carefully run over the surface of the mixture, the object of

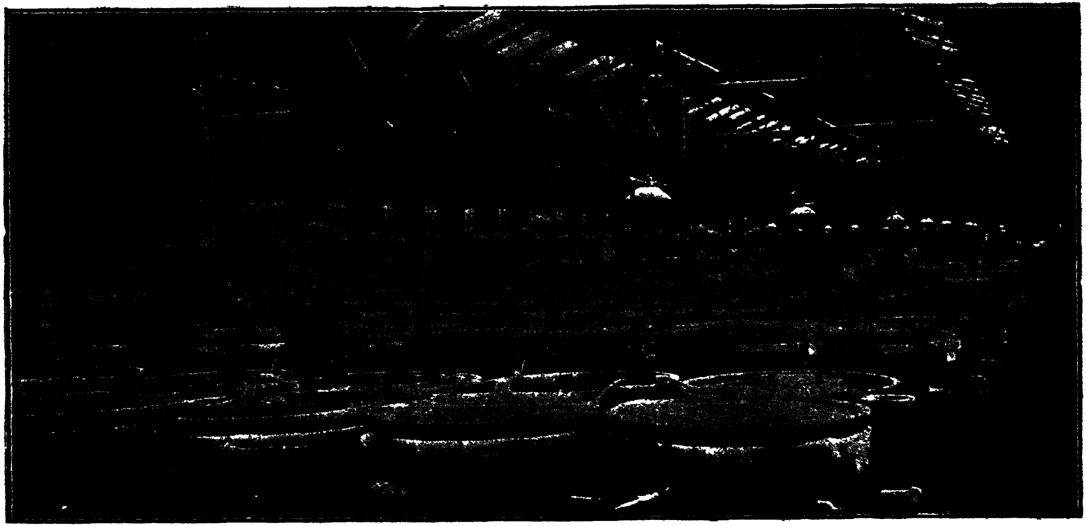

PLATE NO. 3

COTTON NITRATING ROOM, H.M. FACTORY, GRETNA

Showing Earthenware Nitrating Pans, in batteries of four, with water connections above and acid connections beneath this being to absorb the nitric acid vapour and nitrous fumes which would otherwise be given off. The nitration requires altogether from twenty minutes to an hour. The mixed acid used is generally cooled down to about five degrees centigrade in order to avoid any danger in the nitration.

After the nitration is finished, a valve at the bottom of the vessel is opened, and the acid is allowed to drain away, water being introduced at the top of the vessel in such a way as to keep it always full. This process is known as " Displacement," and it is found that by this means it is possible to remove much more of the acid than would drain out if the cotton were simply removed directly from the nitrating vessel. The water added does not mix with the spent acid if the displacement be carried out slowly and carefully. (See Plate No. 3.)

The nitro-cotton prepared by the earlier workers was found to decompose after being kept for some time, and this decomposition frequently led to explosions. It was eventually discovered that these were due to traces of acid left in the product, and that all danger on storage could be avoided if the nitro-cotton were completely freed from acid by careful washing. The product from the nitrators is therefore treated repeatedly with boiling water, each wash lasting for many hours. Towards the end of the washing, it is usual to add chalk to destroy the last traces of acid. (See Plate No. 4.)

The washed cotton is then carried, by means of a stream of water, to the beating and potching machines, in which it is worked into an absolutely uniform and loose condition, and is freed from any traces of grit, dirt, or foreign matter which may be present. From these machines it is pumped in the form of a fine slurry with water into enormous blending tanks, in which large quantities are mixed together in order to smooth out

Plate No. 4

NITRO-COTTON WASHING ROOM, H.M. FACTORY, GRETNA

Showing Wooden Washing and Boiling Vats. A charge is being removed after washing from the open vat in the foreground. The washing process requires several days.

any differences in the various lots. This slurry is then pumped to presses or centrifugal machines, in which most of the water is removed, and at this stage a wet nitro-cotton containing about 50 per cent. of water is produced.

This wet cotton can be handled with safety, whereas dried nitro-cotton is extremely dangerous to handle. Dry nitro-cotton very readily ignites, and may explode with great violence. The product from the presses is therefore stored and transported without further drying, and receives no other treatment until it arrives at the site at which it is to be transformed into finished explosive.

Preparation of Nitro-glycerine. On account of the great sensitiveness of this explosive, its manufacture must be carried out with the most stringent precautions. The nitration and subsequent handling are carried out in entirely separate units of the factory, which must be situated several hundred feet from other factory buildings, and enclosed by means of earthen mounds. The nitration is carried out in cylindrical vessels fitted with cone-shaped tops, the apex terminating in a pipe. These vessels are fitted with cooling coils in which refrigerated brine is circulated. They will generally produce rather more than a ton of nitro-glycerine at each charge.

The mixed acid is introduced into the vessel and the cooling brine turned on. When the temperature is low enough, the glycerine is introduced, being forced by compressed air through finely divided injector nozzles into the acid. The object of this is to ensure that the glycerine is introduced in a spray so fine that every particle reacts immediately with the mixed acid, and no unchanged glycerine is allowed to accumulate. The rate of admission of the glycerine is adjusted to keep the temperature at a safe level. If any quantity of glycerine were allowed to accumulate in the nitrator, the action, when once set in, would proceed with increasing violence, and would quickly be beyond control. Many disastrous explosions have occurred in this way. In order to minimize the danger as far as possible, each unit is provided with a big drowning tank kept filled with water, into which any nitration charge is at once allowed to flow by opening a cock, should it appear, by the evolution of red nitrous fumes and a rise in temperature, that the reaction is likely to get out of control.

When all the glycerine has been introduced and the action completed, the contents of the vessel are allowed to stand until separation has occurred. The nitroglycerine is much lighter than the spent acid, and therefore forms a separate layer on the surface. In order to avoid the danger of passing it through cocks or valves, the nitro-glycerine is floated upwards through the top of the vessel by introducing at the bottom the necessary quantity of spent acid from a previous operation. The nitro-glycerine runs through an open gutter to the washing house, in which it is washed repeatedly with water containing soda to remove all traces of acid. After washing it is allowed to settle, and is then added directly through a measuring vessel to the necessary quantities of guncotton in the proportion to form cordite.

Great care must be taken to observe the most scrupulous cleanliness in the whole nitro-glycerine area, and to avoid accumulation of the explosive at any point. Since the wash water usually carries away traces of nitro-glycerine it is usual to run this to a large reservoir or pond, in which a dynamite cartridge is exploded from time to time to destroy any small quantities of the nitro compound before sufficient can accumulate to become dangerous. The floors of the nitration and wash house must be kept free from all grit or dirt, and any liquid spilled must be carefully mopped up by means of waste, which can then be burned in very small quantities. Operatives must wear special clothing and rubber boots, and no metal implements may be used except under the supervision of some responsible official. Similarly, no repairs may be carried out nor any departure from normal procedure made without the authority of the person in charge. It is remarkable that in spite of the great danger attending the manufacture and handling of nitro-glycerine, very few accidents occurred during the war, though many thousands of tons were manufactured, and the great majority of the operatives were of necessity entirely unfamiliar with its properties and the methods of handling it.

Nitro-glycerine is made in peace time for the preparation chiefly of dynamite for use as a blasting explosive in mines, in the construction of tunnels, cuttings, etc. Dynamite is made by absorbing nitroglycerine in a porous kind of earth called kieselguhr, which has the power of absorbing nearly twice its weight of the liquid. Dynamite cartridges are generally exploded by means of a detonator. Many thousands of tons are used each year in the gold mines of South Africa alone. The rock is drilled to the necessary depth and the cartridge is inserted with the detonator and exploded from a distance by means of a fuse.

Preparation of Cordite and Nitro-cellulose Tape, N.C.T. The finished propellant explosives are obtained by working the nitro-cellulose, with or without addition of nitro-glycerine, into the form of a gelatinous dough, which is forced through die-plates, provided with holes of the size and shape suitable for the powder required.

The cotton, which is received in the wet condition, must first be freed from moisture. This is accomplished either by exposing it to the action of warm air in drying stoves, or by replacing the water in it by alcohol. The latter operation, which is known as Dehydration, is effected by compressing the cotton into a compact cake in hydraulic presses of great strength. The plunger of the press is withdrawn, sucking in alcohol, and then by a second compression this is forced through the cake, expelling the water, and leaving the cotton saturated with alcohol. If cordite is to be made, the dried or dehydrated cotton is taken in rubber bags to the nitroglycerine hills, and the necessary quantity of that liquid measured in. (See Plate No. 5.) The paste so formed, or the cotton itself, if N.C.T. is to be made, is then taken to the incorporating house, in which it is worked up into a uniform dough in big mixing machines, the necessary quantities of ether and alcohol being added gradually.

The quantity of alcohol used is adjusted according to whether the cotton has been dried or dehydrated. Towards the end of the incorporation some substance is added, the function of which is to minimize danger of explosion by decomposition of the finished explosive on storage; usually vaseline or mineral jelly is used for this purpose.

The dough is now taken from the incorporating house to the press house, in which it is forced through perforated plates by hydraulic pressure. For rifle powder the perforations are very small, and the mixture comes out in the form of fine cords, of about the thickness of twine. For artillery the perforations are bigger, and are varied in shape, N.C.T., which is more especially used for cannon powder, being forced, as the name implies, into flat ribbon or tape of varying thickness.

Plate No. 5

NITRO-GLYCERINE HILL, H.M. FACTORY, GRETNA

Pouring on to Nitro-Cotton contained in Rubber Bags. Operatives are wearing rubber caps and boots. Note absence of cocks and valves, and of all metal implements.

For very heavy guns the cord or tape is made very thick, the object being to get a smaller proportion of surface to weight, so that the powder burns more slowly.

The cord or tape is cut into suitable lengths and is taken to the solvent recovery stove, in which the solvents used in the incorporation are driven off. This operation usually takes several days, especially for the larger sizes, for naturally too high a temperature may not be employed. The finished explosive is then taken to blending houses, in which large quantities are mixed together to ensure uniformity, and finally to the magazines. (See Plate No. 6.)

Since the solvents employed in the incorporation are costly, it is usual to recover them as far as possible. Large quantities escape in the form of vapour in the press houses, and most of the remainder is driven off in the drying stoves. The air from these is therefore drawn by means of large fans through vessels in which it is brought into contact with some liquid capable of taking up the vapours of the solvents, and this liquid is afterwards heated in order to drive off the vapours, and recover them in a form in which they may be used again. Since all the solvents used are very volatile, having vapours very readily inflammable, great care must be taken in handling them to avoid fires. A noteworthy example in which presence of mind averted what might have been a disastrous explosion was reported from one of the national factories during the starting up of the cordite plant. Ether, for use in the incorporation, was pumped through a pipe line from the ether store to the incorporating house, in which it was drawn off to the incorporating machines. Ether is extremely volatile, boiling at about 100 degrees F., and its vapour ignites very readily and burns fiercely. On this occasion, a spark produced by the discharge of electricity generated by

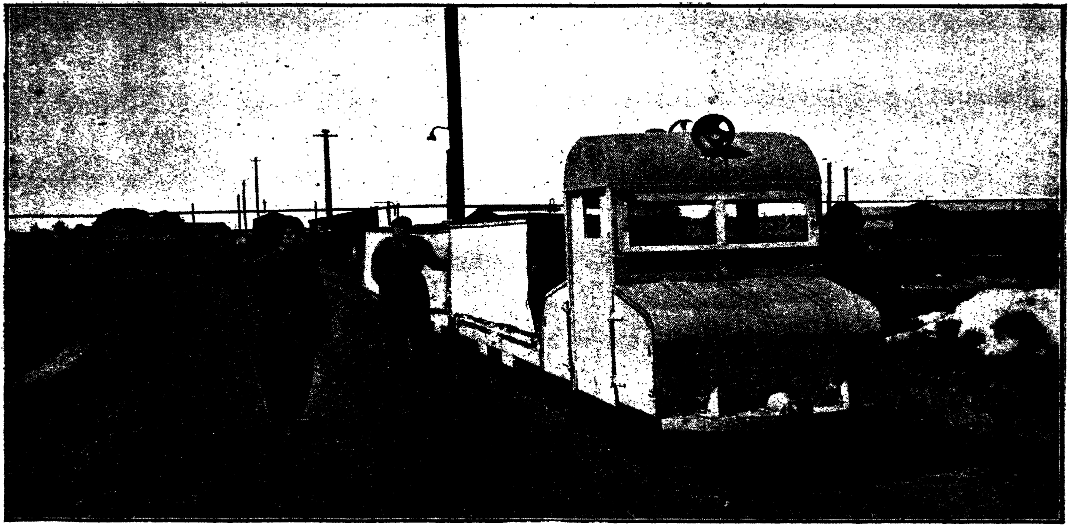

Plate No. 6

ELECTRIC LOCOMOTIVE AND TRUCKS FOR TRANSPORTING CORDITE, CORDITE AREA, H.M. FACTORY, GRETNA

Note the great distances between the various Houses the belt driving the machine, ignited the ether vapour, and almost instantly the whole building was in flames. The operator of the machine was a girl totally new to the work, but she retained sufficient courage and foresight to turn off the tap on the ether pipe before escaping from the building. But for this act nothing could have prevented the delivery into the building of many tons of ether, which would certainly have caused a fire and explosion which would have caused enormous damage and loss of output at a time when every pound of cordite was urgently needed. As it was, the fire was quickly brought under control and relatively little damage was done.

An explosive known as Ballistite is also prepared from nitro-glycerine and nitro-cellulose. The process employed has the advantage that the nitro-cellulose need not be dried or dehydrated, since the incorporation is carried out in water. The nitro-cellulose is beaten up in water and nitro-glycerine added gradually. The two mix to form a sort of paste, which is readily freed from most of the water, and is then dried and worked up into sheets of a horn-like appearance and consistency by repeated and lengthy treatment between warmed rollers.

The finished explosives are subjected to very rigorous tests before being passed for use. These include tests for moisture and volatile matter, stability, composition, and actual firing tests. Great attention is also paid to the uniformity of the product, for on this depends the pressure produced in the gun, and therefore the possibility of firing with precision. Relatively large quantities may be rejected as a result of these tests, and these must be returned to the factory for further treatment. This usually consists in crushing the material, and re-incorporating it with fresh solvent, after which it goes through the press house, drying stoves and blending house in the same way as new material. Large quantities of partly finished product also accumulate on the factory itself, especially in the cutting of the cords or tape coming from the presses. All this material is re-worked in the same manner. Very little waste should occur, and only material which has been allowed to become contaminated with grit or dirt is regarded as waste. Naturally, however, any material to which suspicion attaches must be rejected, for the introduction of grit or dirt into any part of the machinery might mean a fatal explosion. All waste material is collected and destroyed on a special burning ground some distance from the main units.

CHAPTER V

PREPARATION OF THE HIGH EXPLOSIVES

Picric Acid or Lyddite. Picric acid is generally prepared from phenol or carbolic acid, which occurs in coal tar, and which can be also itself synthesized from benzene. In addition, picric acid can be manufactured from benzene by another method, which has recently come into prominence from the fact that the intermediate substances which must be made in the process are of great value in the dye-making industry.

The old method of making picric acid from phenol consists in first treating this material with strong sulphuric acid, in which it dissolves, forming what are known as phenol-sulphonic acids, and then treating the solution with weak nitric acid. The first operation, which is known as sulphonation, is generally carried out in big lead-lined tanks fitted with stirring gear. The mixture becomes very hot, and is usually allowed to cool before being treated with nitric acid. This second operation, which constitutes the nitration, is generally carried out in earthenware pots from 2 to 3 ft. deep and about 18 ins. in diameter. On account of the use of these vessels, the process is generally known as the Pot Process. The nitric acid must be added very gradually, in fact, almost drop by drop, for the reaction is very vigorous, and enormous volumes of red nitrous fumes are evolved. In the older works it was the custom to start the nitration in the evening, and allow the nitric acid to drip in slowly over night. In this way the large volumes of poisonous fumes were given off during the night when no workmen were about. Obviously such a procedure could not be employed for manufacture under war conditions, for besides the loss of time and delay involved, the nitrous fumes, which constitute so great a nuisance if allowed to escape into the air, represent a serious loss of nitric acid. In the plants erected to work this process during the war, therefore, the pots were provided with tight fitting lids, to which were connected pipes by means of which the nitrous gases could be drawn to absorption towers and reconverted into nitric acid for further use.

After the nitration is complete, and the mixture has been allowed to cool down, the liquid remaining in the pots is drained off by means of a syphon. This liquid, which consists of dilute sulphuric acid containing small quantities of nitric, picric and phenol-sulphonic acids, was before the war allowed to run to waste, on account of the expense and danger involved in reconcentrating it. During the war, however, the shortage of sulphuric acid made it necessary to recover this waste acid, and in most works this was successfully accomplished by means of cascade concentrators.

The picric acid which is left in the pot after the spent acid has been removed is shovelled out by means of wooden spades and immersed in water in lead-lined tanks. After two or three washings with water to remove most of the adhering sulphur acid, it is removed to the washing plant, which consists of a series of wooden tanks in which the picric acid can be treated with successive quantities of water. In the most modern plants, it is customary so to arrange the washing vessels that the picric acid can be easily transferred from one to the other, and the water used for washing towards the end of the operation is not thrown away but is used again for the first washings of the next batches coming from the nitration plant.

The pot process is open to many serious objections as a means of obtaining large scale production, and during the war another process was devised for making picric acid which is much on the lines of the process, brought into use for making T.N.T. In this second process, known as the Strong Acid Process, the phenolsulphonic acid mixture is added to a mixed nitric and sulphuric acid contained in very large cast-iron pots fitted with stirring gear and with cooling coils. Owing to the control of temperature which the coils permit, the operation can be carried out very much more quickly, and with practically no loss of nitric acid in the form of fumes. As from one to two tons of picric acid can be made at one time, the process is very much quicker as well as very much more economical than the earlier method. After the nitration, the picric acid is separated from the sulphuric acid left by filtration, and the spent acid concentrated. The picric acid is then washed as before.

The process for making picric acid from benzene without the manufacture of phenol as an intermediate body consists of four stages. In the first, benzene is treated with chlorine to make chlor-benzene. This involves the manufacture and handling of large quantities of chlorine gas, the chief industrial use of which is for the manufacture of bleaching powder. The process can therefore best be carried out in works already equipped for the manufacture and handling of this very poisonous and corrosive gas, and affords an illustration of the great advantage in the chemical industry of developing very large works by combination of several processes. This has been the principle adopted by the heavy chemical industry in England, which deals with the manufacture of sulphuric acid, washing soda, bleaching powder, etc., and by the fine chemical industry in Germany, which prior to the war had secured what was virtually a monopoly of the manufacture of synthetic dyes, drugs and perfumes.

In the second stage the chlorbenzene is nitrated to dinitrochlorbenzene. This nitration is carried out in the ordinary manner by means of mixed acid in large iron vessels fitted with cooling and stirring apparatus. In the third stage, the dinitrochlorbenzene is treated with caustic soda, which converts it into dinitrophenol. In the fourth stage, the dinitrophenol is treated with a very strong mixed acid, which converts it into trinitrophenol or picric acid.

The picric acid prepared by any of these methods is thoroughly washed with cold water until free from all traces of sulphuric acid, and is then dried. The drying sheds consist of small buildings heated by means of steam pipes, and provided with glass shelves on which the picric acid is spread out. It is raked over from time to time until free from moisture, and is then sieved to remove any lumps. The fine yellow crystalline powder so obtained is packed in canvas bags, which are put into wooden boxes and stored in the magazine. Very stringent regulations govern the drying and storage. Not more than a specified quantity, usually 2,000 lbs., may be in any one building at any time, and specified distances must separate each building. Picric acid is in fact one of the most dangerous of the high explosives. It very readily attacks metal and common alkaline materials, forming salts which explode very easily when struck. Lead is especially easily attacked, and the lead salt is very dangerous, detonating even when ground between hard surfaces.

The bright colour and strong dyeing properties of this explosive render those engaged in its manufacture, as well as the factory and even the district in which it is carried out, easily recognised. The site of a picric acid plant is usually covered with a bright yellow surface colouration. The skins and clothes of the operatives and even the skins of horses transporting materials in and out of the works show the same bright hue, and all water effluents and drainage passing through or from the works take on the same novel appearance. It is a mild poison, but one not easily absorbed, and though it is unpleasant to handle, few serious cases of posioning have been recorded. It has, however, a fatal effect upon fish, and the disposal of effluent waters from picric acid works during the war caused considerable difficulty on this account. The view was generally taken, however, that the needs of the moment were for explosives rather than fresh water fish.

Preparation of T.N.T. The nitration of toluene to T.N.T. is seldom carried out in one operation. The action of mixtures of nitric and sulphuric acids upon toluene and other members of the class to which it belongs can be carried out in such a way as to give series of nitro-bodies. With a mixed acid containing about 15 per cent. of water and only just the required amount of nitric acid, mononitrotoluene, or M.N.T., is produced. If a higher proportion of nitric acid is employed, dinitrotoluene or D.N.T. is obtained. The preparation of T.N.T. requires a very strong mixed acid, that is, one containing very small quantities of water only and a relatively very high proportion of nitric acid. Since water is produced at each stage of the nitration, it is obvious that for the final stage, where the acid is required to be strongest, it would already be diluted with the water produced in the formation of the mono- and di-nitro bodies, and would have already lost much of its nitric acid contents. For this reason, it is usual to carry out the nitration in two or three stages, which allows of considerable economy in acid usage, and also permits of a useful operation known as detoluation.

After the final nitration which produces T.N.T., the spent acid contains an important proportion of the nitro-body. In the two stage process, this acid, after the separation of the bulk of the T.N.T. produced, and before being pumped to the waste acid plant, is washed with the M.N.T., which is made separately, and which is then used for making the next batch of T.N.T. In this operation, which is known as detoluation, the M.N.T. washes out from the spent acid almost all of the T.N.T. left in it, and since this M.N.T. is itself used later for making T.N.T., no loss of the latter takes place in the spent acid.

The various operations are all carried out in big cast iron nitrators, fitted with mechanical stirring plant, and with coils through which steam and water can be passed in order to heat or cool the reaction mixture as desired. (See Plate No. 7.) For making M.N.T., the measured quantity of toluene is run into the vessel, and the necessary amount of mixed acid is added gradually, the mixture being cooled by passing water through the coils. The nitration takes place with considerable evolution of heat, and if great care is not taken in running in the acid, the reaction may become violent and the contents of the vessel froth and fume over. For this reason it is essential to have good stirring, so that the acid reacts as it is added, and no accumulation takes place. The frothing over is generally not very dangerous, though in extreme cases it may lead to fires, but it is extremely unpleasant by reason of the dense volumes of nitrous fumes given off, and a great deal of cleaning up must be done in and around the plant before operations can be resumed. After the nitration is completed, the stirrer is stopped and the mixture allowed to settle. The M.N.T., being considerably lighter than the spent acid, rises to the surface. The contents of the vessel are

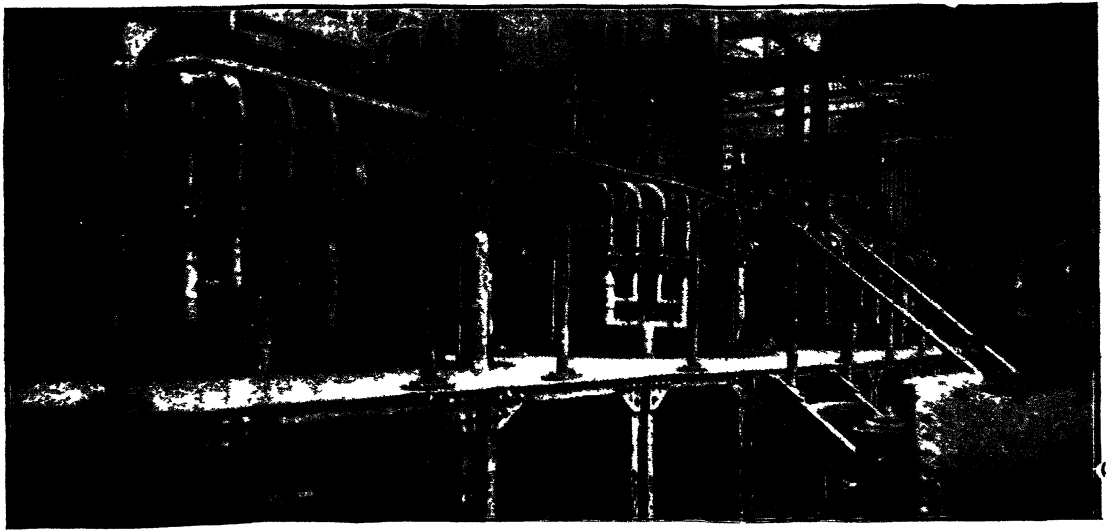

Plate No 7

T.N.T. NITRATION HOUSE, H.M. FACTORY, QUEEN'S FERRY

Showing Four Nitration Pans, fitted with agitators and coils for temperature control then run off slowly through a sight box, by means of which the point at which the acid is followed by the M.N.T. can be observed, and the latter diverted to a separate vessel.

The nitration of M.N.T. to D.N.T., or direct to T.N.T., is carried out in much the same way, except that it is usual to add the body to be nitrated to the acid contained in the pot, instead of adding the acid last, as in making the M.N.T. As T.N.T. is solid at the ordinary temperature, it is necessary to keep the mixture hot after the nitration, in order that the T.N.T. may separate from the mixed acid in the liquid condition. The liquid T.N.T. is separated from the spent acid in the same way as in the case of M.N.T., that is, after settling the mixture is run through a sight box, and when the liquid nitro-body is observed to come through after the acid has all passed, it is diverted directly to the washing vessels. In these it is washed repeatedly with boiling water, until all the acid has been removed, after which it is allowed to settle, and is then pumped, still in the liquid condition, to driers, in which it is heated to remove the water. It is then allowed to flow slowly into big trays in which dip the lower end of big revolving metal cylinders or drums. These drums are cooled by means of a current of cold water which runs through them. The cooled surface causes the liquid T.N.T. to solidify upon it, and this skin of solid T.N.T. passes round with the drum until it meets at the other side a knife set close to and parallel with the surface of the drum, which scrapes it off in fine flakes, which are allowed to fall directly into a hopper, from which the flaked explosive is drawn off into linen bags. This operation, which is known as granulation, forms a very important and convenient method of transforming the liquid nitro body into a powder ready for packing. (See Plate No. 8.)

PLATE No. 8

T.N.T. GRANULATING AND PACKING HOUSE, H.M. FACTORY, QUEEN'S FERRY

The Granulating rolls are on the floor above, the T N T falls down the hoppers and is received in linen bags resting in wooden boxes Note conveyor and weighing machine Operatives wear respirators

During the war a very ingenious method of nitrating M.N.T. to T.N.T. continuously was elaborated on one of the national factories. In this method M.N.T. was allowed to flow continuously into a vessel at one end of a series of similar vessels, and was caused to flow right through the series. Nitric acid was allowed to flow in at various points, whilst at the end, remote from that at which the M.N.T. entered, fresh sulphuric acid was allowed to run in. The M.N.T. became gradually nitrated during its passage through the apparatus, and a continuous flow of T.N.T. was allowed to escape from the end at which the sulphuric acid entered. The effect was thus to cause M.N.T. to flow continuously against a current of acid, which became more and more dilute as it passed through, whilst the M.N.T. became more and more highly nitrated during its passage, the nitric acid required being allowed to flow into the various vessels, with the result that T.N.T. escaped at one end, and a spent acid washed almost free from nitro body overflowed at the other end. This plant produced 50 tons of T.N.T. per day with a minimum of labour and difficulty.

On much the same principles, a method of continuous washing was worked out on the same factory, the T.N.T. to be washed being caused to flow in counter-current against a stream of boiling water, thus effecting very thorough washing with a minimum usage of water and with a minimum of trouble. Drying was also made continuous by allowing the washed T.N.T. to flow slowly through channels heated by means of steam passing through the hollow walls. As the flaking process was also continuous, the manufacture of T.N.T. on this particular factory may be said to have afforded a very good example of the advantages of continuous operation, The T.N.T. obtained by these processes, though suitable for use in shell filling, is not absolutely pure, that is, it contains small quantities of other substances, chiefly nitro-bodies, which affect its properties, and especially somewhat diminish the ease with which it may be detonated. When it is used for shell filling, therefore, it is necessary to put into the shell, next to the fuse, a quantity of highly purified T.N.T., which, being more readily detonated, serves as a primer to explode the main quantity. This highly purified T.N.T. was generally obtained previous to the war and during its early months by recrystallizing the impure substance from benzene or some other suitable product. The impure explosive was dissolved in the boiling solvent, and the solution filtered and allowed to cool again. The T.N.T. being less soluble in the cold solvent than it is at the boiling point, separates out in fine crystals, whilst the impurities remain behind. During the war, however, this process was found too tedious for the large quantities required, and a new method, known as the "Sulphite Purification" was evolved. In this process the solid T.N.T. was strongly agitated with a solution of sodium sulphite, which is obtained as a bye-product in the manufacture of phenol, and which has the property of dissolving out the impurities, leaving a very good quality T.N.T., which is separated by filtration, washed and dried in the usual way.

The finished T.N.T. is packed in linen bags, each containing 50 lbs. weight, which are then packed into wooden boxes. These boxes are specially made; no nails are used in their construction, the sides and bottoms being dovetailed together, whilst the tops are held in position by brass screws. On the larger factories, special box-making plants were erected, capable in the aggregate of making nearly 20,000 boxes per day.

Preparation of Tetryl. The starting point of the manufacture of tetryl is dimethylaniline, a substance which is prepared from aniline, and which has considerable importance as an intermediate body in the manufacture of dyes. This substance is dissolved in about ten times its weight of strong sulphuric acid, and the solution allowed to flow gradually into the necessary amount of strong nitric acid contained in an enamelled iron vessel, fitted with stirring gear, and provided with a jacket through which cold water can be circulated. The reaction is extremely vigorous, and great care must be taken to add the dimethylaniline solution very gradually in order to keep the action under control. It is usual to control the flow of the solution by means of a handle fitted with a spring, so arranged that if the operator releases his hold the handle is pulled back and the flow cut off. After the nitration is complete, the tetryl is separated from the spent acid by filtration. The filter consists of a shallow earthenware vessel filled with finely-divided quartz or coarse sand, covered with a perforated plate of lead. The acid runs through the sand and escapes by means of a pipe from the bottom of the vessel, whilst the solid tetryl remains on the lead plate. In some factories it was customary to allow the spent acid to run to waste, as the small quantity of tetryl which it contains renders it dangerous to handle. It may be recovered, however, by being diluted and allowed to stand for several days, when most of the tetryl it contains rises to the surface and may be skimmed off, leaving a spent acid which may safely be denitrated and concentrated for subsequent use.

The tetryl left on the filter is transferred in small quantities at a time to a drowning tank filled with water; the large quantities of waste acid which are mechanically held by the solid particles render this an operation which must be carried out slowly and carefully. The tetryl is then washed repeatedly with boiling water, until freed completely from acid. (See Plate No. 9.) It is then dried by exposure in shallow glass-bottomed trays to the action of warm air in buildings provided with steam pipes. The material so obtained is suitable for many purposes, but where purified material is required further treatment is necessary. This consisted originally in recrystallation from acetone, but owing to the low boiling point and highly inflammable nature of this solvent the operation is rather dangerous. During the war a process of recrystallisation from nitric acid was devised and put into operation at one of the national factories. The crude tetryl is treated with strong nitric acid, and the solution filtered; water is then added gradually until most of the tetryl has been precipitated. This is then filtered off and washed and dried in the usual way, whilst the nitric acid left is used for the nitration of a further quantity of the dimethylaniline.

Tetryl is a much more dangerous substance to handle than T.N.T., and only very small quantities may be employed in each operation. The washing, drying, and sieving houses are all mounded for protection in case of explosion, and the precautions to be observed throughout are much more rigorous than in the case of T.N.T.

Other Nitro-Explosives. Practically no other nitro-bodies than those considered above were made in England on a large scale for military purposes during the war. On the Continent, however, the supplies of toluene and phenol were not sufficient for military requirements, and large quantities of other nitro-bodies were manufactured. The commonest of these were dinitrobenzene, dinitrotoluene, dinitronaphthalene and trinitroxylene, though several lesser known nitro-compounds were also made in varying quantities, especially in Germany. The manufacture of these bodies is carried out on much the same lines as the preparation of those already described, the only variations being such as are rendered necessary by the physical properties of the substances handled. In the nitration of napthalene, however, which is itself a solid, this material is added to the mixed acid contained in the nitrator by means of a hopper fixed to the cover, and the resulting nitro body is separated from its spent acid by filtration. Trinitroxylene, the melting point of which is too high to permit of convenient handling in the liquid condition, is extremely difficult to filter from the spent acid, owing to the fact that it does not separate from the reaction mixture in well-defined crystals. Dinitrobenzene and dinitrotoluene are noteworthy from the fact that they are somewhat poisonous, and the manufacture involves considerable danger to the operatives. This is a property which is, indeed, common to a greater or lesser extent to all nitro-bodies. These compounds are generally absorbed to some extent into the system through the skin, and proper safeguarding of the operatives engaged in their manufacture can only be effected by the utilization to the fullest possible extent of mechanical devices for handling them.

Manufacture of Ammonium Nitrate. In consequence of the enormous demands for this material occasioned by its use as an important constituent of high explosive mixtures during the war, the best methods of preparation could not immediately be put into operation. Prior to the war there was practically no demand for this material, and no method for producing it on a large scale had been elaborated. The simplest method consists in the treatment of nitric acid with ammonia, but

Plate No 9

TETRYL NITRATION HOUSE, H.M. FACTORY, QUEEN'S FERRY

The Nitrators are beyond the wall on the right of the picture. Against the wall are the filters, the vessels in the centre are the drowning and washing vats this is also the most expensive and probably the most troublesome except on factories equipped for the synthetic preparation of nitric acid by the Haber-Ostwald process, none of which were in operation outside Germany. In that country the manufacture of ammonium nitrate by this method presented no great difficulty once the process was thoroughly established, since ammonia is normally produced at one stage, and part of this can be reserved and used to neutralize the nitric acid produced from the remainder. Owing to the cost, however, the neutralization method was not used to a great extent in England, and we were forced to seek other methods. During 1915 and 1916 three valuable methods were worked out by Messrs. Brunner Mond & Co., the great alkali manufacturers of Cheshire, who produced by far the greater proportion of the ammonium nitrate made in England for war purposes.

The first method involves the manufacture of calcium nitrate from calcium chloride and sodium nitrate. Calcium chloride is produced in enormous quantities as a bye-product from the Ammonia-Soda Process for the manufacture of washing soda, a process which was first introduced and successfully worked on the large scale in this country by Messrs. Brunner Mond. The calcium chloride solution is concentrated and treated with sodium nitrate; the resulting solution is filtered to remove the sodium chloride which separates, and concentrated until, on cooling, it becomes solid. The body so obtained is a compound of calcium nitrate and water, which is directly used for the manufacture of ammonium nitrate by treatment with ammonium sulphate.

The second method consists in a modification of the ammonia-soda process itself. In this process, ammonia, carbon-dioxide and common salt or sodium chloride, are caused to react with the production of sodium carbonate and ammonium chloride. Normally this ammonium chloride is treated with lime, thus regenerating ammonia for further use in the process, and forming the calcium chloride which constitutes a normal bye-product of the industry, and which was used in the calcium nitrate method for making ammonium nitrate outlined above. If sodium nitrate be substituted for sodium chloride in the ammonia-soda process, and the conditions be suitably modified, ammonium nitrate is formed in place of ammonium chloride. This modification was brought into operation by Messrs. Brunner Mond, and very large quantities of ammonium nitrate were produced in this way.

The third method arose from a simplification of the calcium nitrate method. Apart from calcium chloride, the materials used in that process are sodium nitrate and ammonium sulphate, and the calcium nitrate really only serves as an intermediate body in the reaction of these two. After a most exhaustive study of the physical chemistry of the problem, the chemists of Messrs. Brunner Mond succeeded in working out the conditions under which sodium nitrate and ammonium sulphate could be made to react with production of sodium sulphate and ammonium nitrate, and this method, when put into operation on the large scale, proved to be the cheapest and most satisfactory of all.

The ammonia and ammonium sulphate required for these various processes were obtained almost entirely by the destructive distillation of coal in gas works and coke ovens. The ammonium sulphate produced in gas works is ordinarily used as a fertilizer, whilst the chief use of sodium nitrate in peace time is also for agriculture. The quantities of sodium nitrate and ammonium sulphate used for the manufacture of explosives were considerably greater than the quantities of these materials normally used as fertilizers. It can be appreciated, therefore, that agriculture suffered considerably from the diversion of these essential commodities to war purposes, whilst at the same time the peace-time value of the German war factories for making ammonia and nitrates become obvious.

Mixtures Containing Ammonium Nitrate. Among the " Permitted Explosives " licensed by the Home Office for use in mines, and for industrial purposes, are many containing nitrates of sodium, potassium, and barium. The use of ammonium nitrate in explosives of this kind was not uncommon before the war, but its use for military purposes raised a large number of problems for the solution of which no sufficient experience was available. The physical properties of this salt were not well understood, and in consequence great difficulties arose in handling and storing it and in preparing the various mixtures with nitro-explosives which were brought into use during the war. The successful solution of these was largely rendered possible by the exhaustive and painstaking work carried out by the chemists of the Gun Ammunition Filling Department under the direction of Dr. Martin Lowry.

On the Continent, ammonium nitrate was seldom used in a greater proportion than 40 per cent. of any mixture, the chief nitro-explosives used besides T.N.T. being the dinitro-compounds of benzene, toluene, and naphthalene. The preparation of suitable mixtures of these proportions, that is, containing not less than 60 per cent. of nitro-body, is relatively simple, and was generally carried out at the shell filling factories. The nitro body was melted and pumped in the liquid condition into vessels of cylindrical shape with conical bottoms, fitted with stirring apparatus and kept hot by means of steam jackets or careful insulation. The dried powdered ammonium nitrate was then stirred slowly in, and as the whole mass, whilst hot, remained in a semi-liquid or porridge-like condition, filling of the shells could be effected by pouring. The case was very different, however, when larger proportions of ammonium nitrate were used, as was the case in the preparation of amatol in England during the later stages of the war. In this explosive proportions of ammonium nitrate as high as 60 or 80 per cent. were employed, and the problem of preparing uniform mixtures, and of filling these into shells at the required densities, was by no means a simple one.

In the first place, the storage and handling of very large quantities of ammonium nitrate is rendered difficult by the fact that this substance, owing to physical changes which occur very slowly after it has been manufactured, sets into hard rock-like masses. Wooden casks filled with the nitrate were found on arrival at the shell-filling factories to have set so hard that the staves had to be broken away and the mass broken up with pickaxes. It was found, however, that if the nitrate were not entirely dried before despatch, this setting did not take place, and it became customary to despatch the material containing a small proportion of water and to dry it finally at the filling factories. Special railway wagons were introduced into which the powder could be loaded loose, and from which it could be discharged by tilting the body of the wagon on arrival at its destination. The mixing of 60/40 and 80/20 amatol, as the mixtures containing 60 and 80 per cent. respectively of ammonium nitrate with T.N.T. were called, was effected in jacketed incorporating machines, and the methods known as Hot-Filling and Cold-Filling were introduced for filling the shells. The difficulty to be overcome consisted in the fact that in order to secure complete and effective detonation, the contents of the shell must not be below a given density, that is, the weight of explosive for a given shell space had to be raised above a certain minimum limit. This was attained for the larger shells by the use of hydraulic presses, the mixture being simply compressed into place by means of rams. This operation naturally is not unattended with a certain risk, and the presses used were accordingly placed in separate buildings, each carefully mounded to minimize the effects of possible explosion, the controlling levers and recording instruments being operated from outside the buildings.

Another difficulty was found to result from the tendency, in the case of those shells charged by the hot filling method, for the explosive to contract on cooling and so to recede from the immediate neighbourhood of the detonator and primer, so that the fuse was not effective and detonation was only partial or even did not occur at all when the shell reached its destination. A similar trouble arose from what is known as " setback " on firing. This is due to the fact that the sudden impact on the shell when it is fired from the gun reacts first on the metal case and so causes the high explosive contained in the case to settle back towards the base of the shell, and to detach itself from the fuse in the nose. All these troubles had to be over come by careful modification in the design of the shell and in the methods of filling and inserting the fuse, and it was the proud boast of the Gun Ammunition Filling Department that the percentage of " duds," or shells which failed to explode, was lower in the case of the British than in that of any other artillery during the war.

Still another difficulty arose from the fact that on detonation shells filled with amatol containing a high proportion of ammonium nitrate, gave no smoke and made it difficult for observers to secure accurate firing. This is due to the fact that the carbon which forms the black smoke characteristic of nitro-explosives used alone, or with small proportions of ammonium nitrate, is completely oxidized when large proportions of the nitrate are used, so that detonation produces only colourless gases. This difficulty was in turn overcome by using, in filling the shell, small quantities of " smoke powders," which were mixtures especially made up to give a thick smoke on explosion.

The above outline of some of the difficulties encountered in bringing the high percentage amatol fillings into use can be taken as typical of the work which had to be done in almost every section of the activities of the Munitions Supply Department. When it is remembered that the filling constitutes only one part of a shell and that every part—casing, propellant charge, percussion cap, fuse, and primer—must be perfect in design, construction and assembly if the shell is to be effective in use, it will be conceded that war is becoming more and more an affair of organized industry, and that armies and navies will afford no safeguard to a country in the future if its technical and industrial development be not equal or superior to those of other countries.

Chlorate and Perchlorate Explosives. All the explosives so far described are mixtures or derivatives of the nitrates or of nitric acid. There are, however, many other substances so rich in oxygen as to be available, directly or indirectly, for the preparation of the explosives. The chlorates and perchlorates, next to the nitrates, are among the commonest of these compounds, but their use is restricted by the danger which attends it, and which has resulted in some of the worst accidents in the history of explosives manufacture. The salts most often employed are potassium chlorate and perchlorate, and ammonium perchlorate.

Potassium chlorate has long been employed in the manufacture of safety matches, the heads for which consist of a mixture of that compound with red phosphorus and antimony sulphide. It is manufactured by electrolysis, that is, by passing an electric current through a solution of a salt; the perchlorates may be obtained in the same way. The effect of the current is to break up the water of the solution into its elements, hydrogen and oxygen, the former of which is liberated in the gaseous state whilst the latter, under the appropriate conditions, combines with the chloride in the solution to form the chlorate or perchlorate. Besides its use in the manufacture of safety matches, potassium chlorate is used in the preparation of various tabloids for sore throats, as it is a germicide of some power. It is also used for the manufacture of fireworks. It is not itself an explosive, but it is used to some extent in various explosive mixtures to supply oxygen. Ammonium perchlorate, on the other hand, is itself an explosive, and was used during the war for naval and land mines, and in admixture with small proportions of organic substances for shell filling.

Detonating Substances. Modern explosives are as a general rule, relatively insensitive, that is, they are not easily exploded by a direct blow. They are, however, under the proper conditions, very sensitive to the shock produced by another explosion. The relationship is a peculiar one. Each explosive, under given circumstances, will respond to a shock of given intensity, but not to lesser or different shocks. It seems that detonation sets up a disturbance in the nature of a wave, which spreads outwards, and which can be reflected in much the same way as light or X-rays or similar disturbances. Thus the detonation of a fuse at a distance of several yards may be reflected into an explosive mixture, causing it to detonate in turn. For all ordinary purposes, however, the detonator is placed in direct contact with the explosive. A complete shell is provided with two detonators; one, in the percussion cap, is detonated by the blow given when the gun is fired, and sets off the propellant charge which expels the projectile, whilst the other, in the fuse in the nose of the shell, which is ignited by the discharge of the gun, detonates the high explosive filling at an interval after discharge of the shell which can be varied, within limits, at will. The shell can thus be made to explode on its journey, or when it reaches its objective, or after arrival, by suitably setting the fuse. All these variations are employed, the first for shrapnel, which is required to explode in the air over the enemy and discharge the bullets with which it is laden, the second for small calibre artillery shell for field guns, etc., and the third for heavy howitzer and armour piercing shell for destroying entrenched works and armoured forts and ships.

The materials generally used for detonators differ from all the explosives hitherto described in that the decomposition they suffer in detonation is not in the nature of a combustion as between an organic residue and oxygen, but rather a sudden and complete breaking up of an unstable chemical system, which may or may not produce gases. Chemistry has shown the existence of quite a large number of such compounds, but most of them are far too sensitive and uncertain for ordinary use. The acetylides of silver and copper, for example, when in the dry state, detonate on the merest scratch, whilst nitrogen iodide is so unstable that it detonates when touched with a feather. Other organic compounds (*e.g.*, the aliphatic poly-azo compounds) explode when merely poured from one vessel to another, or when shaken in a vessel of which the inside surface is not absolutely smooth.

The compounds most used at the present day as detonators are fulminate of mercury, either alone or mixed with potassium chlorate, and lead azide. These two substances, though stable as compared with some mentioned above, are so sensitive to shocks and blows as to render their manufacture very troublesome. The quantities required, however, as compared with the amounts of the more stable explosives for the detonation of which they are employed, are small, and so the preparation can be carried out with the necessary care. Fulminate of mercury is prepared from mercury, alcohol, and nitric acid; it is a heavy grey insoluble powder. Lead azide is prepared from lead acetate and sodium azide, the latter being obtained by a lengthy process of which the starting point is a compound of hydrogen known as hydrazine. Both substances, after precipitation, are carefully washed and dried, sieved and filled into tiny copper tubes ready for use.

CHAPTER VI

EXPLOSIVES IN WAR AND PEACE

THE use of explosives in normal times, quite apart from the employment of various propellant mixtures for sporting cartridges, is sufficient to make their manufacture a considerable industry, and one of great importance in social development. Foremost among the industries which depend entirely for their success on the use of explosives is mining, and more especially gold mining. The hard quartzite deposits of South Africa, from which so much of the world's gold is extracted, are riven and fissured on an enormous scale by the aid of the nitro-glycerine explosives, dynamite, gelignite, blasting gelatine and the like. In the winning of coal also, explosives are largely employed, and their use in mining will certainly be extended in future. The quarrying of granite and slate is rendered much simpler and easier by the use of explosives. In tunnelling and cutting for road, railway, and canal construction, they are of incalculable assistance, as also for clearing and levelling sites, and all such work. Rather different is their employment in agriculture and fishing. The explosion of dynamite cartridges in lakes and rivers to kill fish and bring their bodies to the surface has long been known and used. More recently it has been found that the explosion of a cartridge buried in the earth of an orchard has a favourable effect on the fruit crop, probably by opening up and aerating the soil round the roots, and an extended use in this direction may be expected in the future. These various applications have created a considerable demand for industrial explosives, and the world's production before the war must have been of the order of a thousand tons a week. Dynamite and the various gelatinized nitro-glycerine and nitrocellulose mixtures were chiefly employed, though the permitted explosives used in British coal mines generally contain sodium or potassium nitrates and aromatic nitro-explosives. For quarrying, the original gunpowder, or black powder is still largely employed.

The outbreak of the war naturally caused an enormous increase in the demand for explosives, and especially for high explosives, which was chiefly met by the manufacture of T.N.T. and ammonium nitrate. Of the latter material the production in England alone reached 5,000 tons a week, whilst the output of T.N.T. reached 1,500 tons per week. The output of propellant explosives reached nearly 2,000 tons per week, chiefly cordite. Naturally these great quantities required still greater quantities of raw material, the necessity for the provision of which brought to the Government and the community some realization of the interdependence of all industrial activities and of the extent to which technical and industrial resources limit, or rather define, naval strength and military power.

The raw materials required have been dealt with in Chapter I. The chief inorganic materials are sodium nitrate, ammonia liquor, and ammonium sulphate, and sulphuric acid. All these are extensively used in industry in times of peace, and more especially as fertilizers, or for the manufacture of fertilizers. Sodium nitrate is applied directly to the soil, as is ammonium sulphate, the quantities of each of these materials used in Europe being several hundred thousand tons per year. Sulphuric acid is used in the manufacture of ammonium sulphate, and of superphosphate of lime, which is also used on an enormous scale as a fertilizer. The demand on these raw materials for the manufacture of explosives, therefore, had serious consequences for agriculture.

The demand for sulphuric acid naturally created a demand for its raw materials, pyrites and sulphur. Pyrites is imported into this country largely from Spain and to a smaller extent from Scandinavia, whilst sulphur is imported from Italy and from America. Roughly, it may be reckoned that a ton of 100 per cent. sulphuric acid requires nearly a ton of pyrites, and as the production of sulphuric acid in peace time in England is of the order of 1,000,000 tons yearly, approximately this quantity of pyrites had to be imported to meet even the normal production. Most of the new plant erected for the manufacture of sulphuric acid during the war consumed sulphur, but additional pyrites-burning plant was also erected so that the demand for imported raw material become enormous. When it is remembered that all the sodium nitrate which was consumed for the manufacture of explosives, and which in England alone during the later years of the war, was about 500,000 tons per annum, had to be transported from Chili, and that the round voyage out and back from this country occupied some three months, some idea of the shipping problem involved in the supply of nitrate, sulphur, and pyrites alone may be formed.

The problem of the supply of the organic raw materials was in some respects even more difficult. Toluene of sufficient purity for the manufacture of T.N.T., for example, was produced in very small quantities only, probably not more than a few tons per week, before the war. The demand for this material rose, in 1917, to about 40,000 tons a year. This demand was met in the first place by installing new plants at all the big gas works of the country to separate toluene from the coal tar, and to scrub out from the coal gas produced the relatively small proportions of toluene which it contained. The result of this scrubbing was to take from the gas benzene and toluene, and small quantities of other compounds to which the illuminating power, and to some extent also the heating power of the gas is due, and the relatively poor quality of the gas supplied for household use during the later stages of the war was largely due to this scrubbing out of the materials required for explosives manufacture. The erection of all this plant, however, and the time taken to bring it into successful operation, caused delays in meeting the demand for toluene, and had it not been for the exploitation of another source of supply, the production of T.N.T. during the earlier stages of the war would have been seriously restricted. This alternative source of supply, which was placed at the disposal of the Allied Governments by the Shell Petroleum and its associated Companies, was the Borneo Petroleum, which had long been known to contain small proportions of benzene and toluene, and other aromatic substances, which had been extracted on a relatively small scale before the war for the manufacture of dyes. These aromatic materials are extracted after a preliminary process of distillation, which serves to concentrate them, by nitration to the mononitro-compounds, which are then readily separated from the unchanged petroleum compounds by another distillation. Many hundreds of thousands of tons of the Borneo spirit were transported from Borneo to England and France, and here again the shipping problem involved was considerable. Distilling plant was rapidly made available by the Shell Company, and practically the whole of the toluene requirements for explosives production during 1915 was met from this source. (See Plate No. 10.)

The development of the supplies of glycerine for the

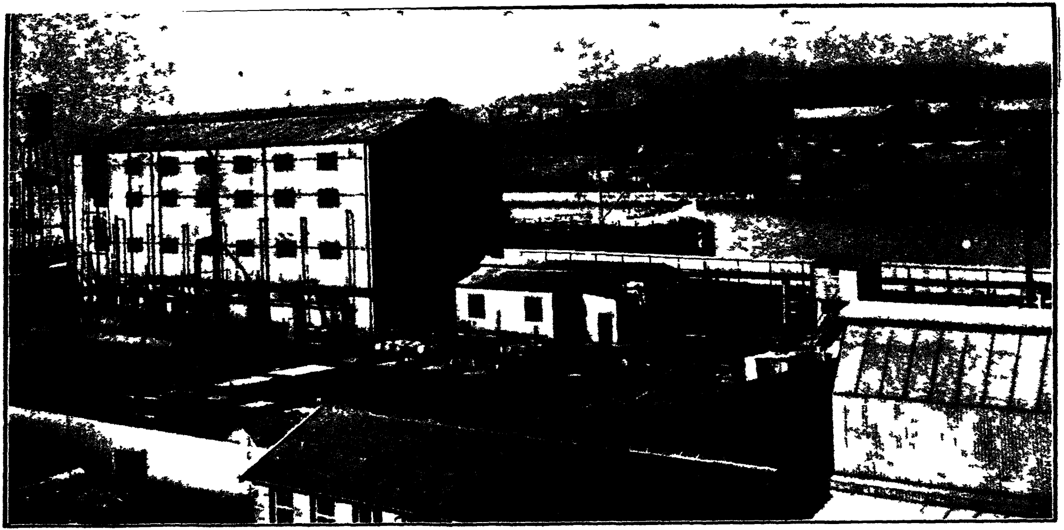

Plate No. 10

H M. DISTILLERY, PORTISHEAD

This Plant concentrated many thousands of tons of Borneo Spirit containing toluene, and supplied much of the toluene used for T.N T during the early years of the war manufacture of cordite has already been mentioned in Chapter I, and it has been shown how the soap and margarine industries were affected. The supplies of solvent for the manufacture of cordite involved problems of even greater complexity, for alcohol, ether, and acetone are substances for which in the pure state, under normal conditions of industry, the demand is not great. For the preparation of cordite, however, the quantities required rose to hundreds of tons per week. Ether is manufactured from alcohol, so that the raw material chiefly required was the latter solvent. The existence of a considerable distilling industry in any country has not always been regarded as an unmixed blessing, but from the point of view of the supply of propellant explosives Britain is fortunate in the possession of considerable resources in this direction. The shortage of whiskey and other spirits during the war was partly due to the enormous demand for alcohol as a solvent in cordite manufacture. The provision of acetone was not, however, so easy, and great difficulties were experienced in obtaining the necessary supplies. A process of fermentation of maize with production of this material was devised, and synthetic processes for making it from alcohol were worked out, but in the main we were forced back on the ancient and primitive method of distilling wood. When wood is heated out of contact with air many valuable substances are produced. The volatile materials driven off include methyl alcohol, or wood spirit, acetone, acetic acid, creosote, etc., whilst the non-volatile residue remaining is charcoal. All these substances are of industrial importance, and therefore most of them directly or indirectly are of importance for munitions supply. Thus, methyl alcohol, besides its use for production of methylated spirit and as a solvent for various purposes, and in the dye industry, is required for the manufacture of the dimethylaniline required for the manufacture of tetryl. Charcoal is extensively used in sugar refining, in sewer traps and filters, and treated with various chemicals was employed in the box respirators which proved so efficient a protection against poison gas. Acetone was required chiefly as a solvent for the gelatinization of cordite; its normal use in industry is as a solvent and for the preparation of certain fine chemicals. Acetic acid finds considerable employment in the production of the cheaper kinds of vinegar, and more recently as a raw material in the manufacture of cellulose acetate for dope for the treatment of aeroplane fabrics, for non-inflammable cinematograph films, and for various associated uses. It may also be used in the manufacture of acetone through calcium acetate; when acetic acid is neutralized with lime, this salt is obtained, and by heating this under suitable conditions, acetone is evolved.

The question of the supply of raw materials was only one of the problems in connection with the production of explosives with which the country was faced on the outbreak of war. Others were the provision of the necessary plant and apparatus, the elaboration of methods of manufacture, the collection and training of staff and labour, and the erection of the necessary magazines and stores. The problems of shell-production and filling, the manufacture of fuses and shellcases, and the production of guns were problems which arose in connection with the effective use of the explosives made, but which need not be discussed here.

The erection of the necessary factories and provision of apparatus was begun soon after the war commenced. One of the biggest explosives factories of the world, in pre-war days, was Messrs. Nobels' works at Ardeer, and this and all other existing factories were soon working at their maximum rates. The limits of production of the existing factories, however, were soon reached, and the erection of new ones became necessary. Much was done by private manufacturers in the direction of extending their works and erecting new plant, but the quantities required were so enormous that the Government decided to proceed with the erection and equipment of National Factories. The first of these was built by the Factories Branch of the Explosives Department at Oldbury, near Birmingham, for the manufacture of T.N.T., and was operated by Messrs. Chance and Hunt, with the co-operation of the Government's experts. The raw material employed was the mononitrotoluene, supplied by the Shell group. The factory started operating in May, 1915—the design work was commenced in February of that year—and was soon producing at the rate of 100 tons a week. The next undertaking was H.M. Factory, Queen's Ferry, near Chester, which was not only built but also operated by the Department. This factory was designed to produce both T.N.T. and nitro-cellulose, and was equipped with what was probably the largest plant in the world for the manufacture of sulphuric acid by the contact process. This was a Grillo plant of ten units, each capable of producing 25 tons of 100 per cent. sulphuric acid per day, giving a total output of nearly 100,000 tons of acid per annum. The output of T.N.T. from Queen's Ferry reached 500 tons per week, and of nitro-cellulose 250 tons per week. The cost of production of T.N.T. was probably the lowest ever reached in the world, and the usage of raw materials per ton of product was reduced to an extent which would hardly have been considered possible before the war.

The next plant erected, H.M. Factory, Gretna, has probably been the subject of as much foolish and ill-informed attack as any other result of Government activity, even in this age of ill-informed and malicious criticism. Gretna was designed to produce 1,000 tons of cordite per week, and was equipped and provided with the staff and services required for this output. In spite of the enormous overhead charges imposed by the necessity of building and supporting a township for its workpeople, and by the fact that at no time was the output demanded from the factory much more than one-half of the quantity it had been equipped and staffed to provide, the cost per ton of cordite produced was as low as at any other factory for which costs are available, and the usage of raw material was considerably lower than on most other factories, whilst many of the units of the Gretna plant established records in chemical efficiency. In addition it must be remembered that the factory represented a reserve of producing power such as no wise supply authority could have failed to provide.

The erection and control of these and many other factories demanded a great deal of research work for the elaboration of new processes and methods. This was undertaken originally by the Research Department at Woolwich Arsenal, though later on the staffs at the various factories undertook a great deal of work of this kind, and many improvements were worked out and applied. The choice of these factory staffs was another of the tasks which had to be undertaken. All the skilled operatives and foremen, to whom much of the work of routine control of plant would normally have been entrusted, were already fully occupied on existing factories, and much of the apparatus and many of the processes were new, so that no experience was available to draw on. In these circumstances the Department of Explosives Supply organized a Staff Bureau, which collected from the universities and training schools of the whole empire engineers and chemists for the various duties of the Department. As soon as the need for skilled engineers and chemists was realized, men of the English-speaking race came from all parts of the world to place their services at their country's disposal, and it is safe to say that in the factories, as in the field, a large share of the British effort was borne by men from overseas.

The duties which had to be undertaken by these professional men, who were for the most part unacquainted with the special problems which had to be faced, and to a large extent unacquainted with any large scale industrial work, were such as were not lightly to be undertaken even under the urgent stimulus which animated them. The manufacture of explosives is always attended with a certain risk, which was very greatly increased by the circumstances. Not only the staffs, but practically the whole of the labour available were unacquainted with the precautions to be taken and, indeed, to some extent with the risks to be faced. Many of the processes were entirely new, calling for special plant and for special methods of operation. The conservation of raw materials, and the absolute necessity of securing immediate output at maximum efficiencies made further demands on the zeal and ability of all concerned, and it speaks much for those responsible to the country for the supply of explosives as well as for those in immediate control on the factories that the guns of the Army were so well supplied.

The conditions in Germany were very different. Chemical industry in that country had been developed, possibly with a view to ultimate military requirements, to an extent which made the supply not only of explosives but also of poison gas a relatively simple matter. Not only were the factories with all the necessary plant in existence, but a relatively enormous trained personnel, skilled in the handling of chemical problems on a large scale, was available, and could be swelled to almost any required extent from the great number of technically trained individuals who were the result of an intensive educational system applied for three generations. Large stocks of explosives had been accumulated prior to the outbreak of war, and processes had been devised and put into operation which, as far as possible, ensured the supplies of essential materials. The German calculations were falsified entirely by the Battle of the Marne. Even so, however, it was not until well on into the year 1915 that the German High Command realized that its preparations had not been sufficiently complete. At the outbreak of war, and in expectation of a short struggle, most of the chemists of the German works had been called up for military service. Towards the end of 1915 and during 1916 most of these were released and were sent back again to the factories, the staffs of many of the works being increased above the pre-war strength. New factories and extensions to existing factories were brought into operation with remarkable speed, much of the plant normally used for industrial purposes being converted for the manufacture of explosives and poison gas.

As the war proceeded, the enemy began to experience difficulties in obtaining suitable supplies of raw material, and during the last year of the war many of the factories were unable to work for more than short periods at a time. Ample supplies of nitrates were ensured by the Haber-Ostwald process, but toluene and glycerine became so scarce as to render impossible the task of meeting military requirements. It was largely due to the shortage of raw materials consequent on the blockade that it became virtually impossible for the enemy to continue the struggle. This shortage operated in every direction and completely sapped the strength of the German armies, but it is certain that even had the enemy been able to obtain supplies of food, he would have been unable to produce the explosives necessary to face the enormous and ever-increasing artillery of the Allies.

CHAPTER VII

CHEMISTRY AND NATIONAL WELFARE

IN the preceding chapters, an endeavour has been made to describe in rough outline the manufacture of explosives, and the problems involved in producing them on the scale required for modern war. In the present chapter it is proposed to show how these problems are but part of a larger problem, that of the successful and conscious development of chemistry as a science and an art necessary for national safety and prosperity, and to show how the explosives industry is intimately bound up with and dependent upon other branches of chemical industry.

Probably few people realize even now the essential part played by chemical technology in almost every branch of productive activity. Chemistry is a highly specialized science, requiring many years of general scientific education, followed by further years of narrower technical study, for its successful assimilation and application. The industries built up on this science require in turn specialized experience, and a great variety of highly complicated plant and apparatus. They deal in one branch with thousands of tons of common and familiar materials, in another with a few ounces of rare, almost unknown, yet equally essential substances. The industrial activities based on chemical science are so varied, and yet so interwoven, and the materials handled are so changed and transformed, and susceptible of such wide variation in application and manufacture, that the efficiency necessary to national well-being and industrial prosperity can be obtained only if great sections of the industry are controlled together, and the industry itself receives direction as a whole. It was the recognition of this necessity for combination and co-ordination of activities which enabled the German chemical industry to reach its pre-war superiority. A short account of the chemical industries, necessarily fragmentary and incomplete, will serve to show how interdependent are its branches. For this purpose, they may be grouped under four main heads, viz., (*a*) Coal and Oils; (*b*) Winning of Metals and Metallic Compounds; (*c*) Heavy Chemicals, and (*d*) Fine Chemicals. This classification is not exhaustive, but covers most of the activities usually classed as chemical.

(*a*) **Coal and Oils.** The industries connected with the mineral, animal and vegetable oils, fats and waxes, and with the winning and distillation of coal, oil-shales, peat and wood may conveniently be considered under this head. Each of them plays an essential part in modern industrial activity, but the greatest and most vital to social well-being are those connected with coal.

The mining of coal itself involves chemical problems, as in the use of safety lamps and explosives, and the handling of inflammable gases, fire-damp, etc. Whilst the treatment of coal produces raw material for explosives, its mining involves their use. The raw coal produced provides heat and power for domestic purposes, as well as for practically every industrial purpose, and its efficient utilization is one of the most pressing problems confronting our civilization. It is agreed that its present use for many purposes is wasteful, and many proposals have been put forward for more economical methods. The most favoured of these recommends distillation under carefully controlled conditions, by which the output of gas, ammonia, benzene products, tar, and smokeless fuel, may be raised to a maximum. All of these materials are to-day produced on an enormous scale in gasworks and coke-ovens, and all of them are vital; their importance has been outlined in Chapter I. The ammonia provides a large proportion of our nitrogenous fertilizers, whilst the tar and benzene products provide raw material for the fine chemical and explosives industries. Benzene is also used as a motor spirit. The coke is used chiefly in metallurgy, in the reduction of iron from its ores, and the gas for power, heat and light.

The distillation of wood has been mentioned in Chapter VI. In addition to the wood-spirit, acetone, acetic acid, creosote, and charcoal obtained by complete distillation, many other products are obtained from various species. The pine and allied trees yield turpentine, rosin, and rosin oils, eucalyptus, etc., whilst the extraction of rubber from the hevea tree, as carried out under modern conditions, is essentially a chemical process. Distillation of seaweed yields various oils, whilst the ash contains potash and iodine salts.

The distillation of oil-shales produces chiefly various grades of lighting and lubricating oils, and of mineral jelly (vaseline) and paraffin wax. These distillations all involve profound chemical change of the material treated, and differ therein from the ordinary distillation or refining of mineral oil or petroleum, which consists for the most part in simple separations of different materials present as such in the crude oil. The products obtained from mineral oils by distillation include (1) very volatile spirits, such as ligroin and petroleum ether, and the " benzine " so much used for cleaning delicate fabrics, and not to be confused with coal-tar benzene; (2) petrol for internal combustion engines; (3) paraffin for lighting and heating, and for some types of oil engines; (4) lubricating oils of all grades, and (5) vaseline and paraffin wax. Some grades of petroleum yield pitch and asphalt instead of vaseline and wax, and many petroleums, such as the Borneo oil mentioned in Chapter VI, contain benzene and toluene and related bodies. The chemistry of mineral oils has yet to be fully worked out, and many valuable products and uses may be found as the result of further research. The refining of mineral oils involves the use of considerable quantities of sulphuric acid and caustic soda.

The animal and vegetable oils are largely used both directly and as margarine for food purposes. The best grades of margarine were originally made from beef suet and mutton fat, but excellent margarine is made nowadays from refined palm kernal oil, soya bean oil, cotton-seed oil, etc. The liquid animal and vegetable fats are transformed into solid fats for this purpose by treatment with hydrogen, as mentioned in Chapter I. Linseed oil is used in very large quantities for the preparation of paints and varnishes, and other vegetable fats and waxes find important applications.

(*b*) **Winning of Metals and Metallic Compounds.** The industries which may be classed under this heading include the mining and separation of all metallic ores and minerals, and the extraction of metals and preparation of their salts. The most important are, of course, the mining of iron ores, and the preparation of the various grades of commercial iron and steel. The utilization of coke in blast furnaces constitutes the most obvious link between this group of industries and the coal group, but a close examination reveals connections at every point.

Consider, for example, the industries connected with lighting. They divide chiefly into two classes, those connected with gas and electricity respectively. Lighting by means of gas was introduced a century ago, but its modern development, incandescent lighting, is not much more than thirty years old, and was rendered possible only by extraction on a commercial scale of the thorium nitrate necessary to make the mantles from monazite sands. This development may be said to have enabled gas lighting to meet on more or less equal terms the competition of electric lighting consequent on the introduction of metallic filament lamps. Thus the mining of monazite sands, and the extraction of thorium nitrate, became of vital importance to the gas and coke-oven industries, and therefore also to the fine chemical industries, which depend on cheap and sufficient supplies of benzene and coal-tar products, and to the manufacture of T.N.T., which requires toluene. Metal filament lamps for electric lighting, on the other hand, are made largely from tungsten, which is also an essential in the manufacture of high-speed tool steels, and other special steels, and which, therefore, forms another connecting or " key " substance. Both monazite sands and tungsten ores occur within the British Empire, yet before the war we obtained both thorium nitrate and tungsten from Germany. Only the imperative necessity of obtaining supplies for war purposes has brought home to us the importance of securing the necessary raw materials and equipping ourselves with the plant and trained personnel requisite to provide us with the finished products.

The manufacture of other common metals, zinc, copper, tin, lead, aluminium, etc., and of the less common ones, silver, mercury, magnesium, bismuth, antimony, nickel, chromium, vanadium, titanium, etc., and of their compounds, and the extraction of the noble metals, gold and platinum, are each in turn dependent upon and necessary to other industries and other aspects of social activity. The common alloys, bronze, brass, white metal, solder—all are essential at some point to industries without which we could not long maintain our commercial status and our social well-being. Consider a few of them. Zinc gives us galvanized iron and tinned iron, and by the action upon it of acids plumbers and welders obtain hydrogen for their blow-pipes. Alloyed with copper it gives us brass, and with other metals various important alloys, whilst its oxide is an important material to chemical and rubber goods manufacturers. Copper gives us brass and bronze, and the metal itself is vital as a conductor in all electrical work. Copper sulphate is used on an enormous scale in agriculture and vine culture as an insecticide and to destroy fungus and bacteria. Without silver and its salts, photography and the cinematograph could not exist. Chromium is an important ingredient of some steels, and its salts are used extensively in tanning, and in the manufacture of fine chemicals. The list could be extended through the whole range of industry.

The production of explosives on the large scale requires in one form or another almost all of these metals, and what is true for explosives manufacture applies in greater or lesser degree to much of chemical industry. Steel, galvanised iron, lead and aluminium are required in the erection of the buildings and plant; zinc and copper alloys for the bearings of almost every moving part of the machinery, copper for all the electrical installation; platinum is used in acids manufacture and in many catalytic processes, mercury is essential for all recording and control instruments, and so on.

(*c*) **Heavy Chemicals.** The heavy chemical industry centres about the manufacture of sulphuric and hydrochloric acids, sodium carbonate or washing soda, sodium hydroxide or caustic soda, chlorine and bleaching powder and superphosphate. Its importance lies in the enormous quantities of these materials normally consumed, and from the national point of view in the fact that sulphuric acid is indispensable for explosives, whilst chlorine was the basis for most of the poison gases used in the war.

The industry originated from the Leblanc process for making sodium carbonate, in which sulphuric acid and common salt are the raw materials, and hydrochloric acid a bye-product. The hydrochloric acid was at first allowed to escape into the air in gaseous form, and as it constituted a great nuisance the Alkali Acts rendered it obligatory on manufacturers to absorb it. An outlet was found for it in the preparation of chlorine and bleaching powder, in which form it became a valuable asset to the process. By the development of the Leblanc process on a large scale, the English manufacturers of the early and middle nineteenth century firmly established the heavy chemical industry in this country. Towards the end of the century, however, the Ammonia-Soda process for making washing soda was successfully established in England by Messrs. Brunner Mond, and with it electrolytic processes for producing chlorine and caustic soda directly from salt were developed, so that the manufacture of sulphuric acid ceased to be essential to the alkali industry. Sulphuric acid is still made for the Leblanc process, but its chief uses now are for making superphosphate and ammonium sulphate, and for use in the tin-plate, explosives and fine chemical industries.

Of the other products of the heavy chemical manufacturers, washing soda is used chiefly for domestic purposes and for making caustic soda; this latter is used in enormous quantities in the manufacture of soap and glycerine, and in the fine chemical industry for making phenol and other intermediate products for dyes. Phenol, it will be remembered, is the raw material for the manufacture of the high explosive, picric acid. Chlorine is used chiefly for bleaching purposes and for making intermediate products for dyes, and in war both directly and indirectly for poison gases. The importance for war purposes of the heavy chemical industries is therefore obvious.

(*d*) **Fine Chemicals.** The manufacture of dyes, drugs, essences, perfumes, photographic materials, pure chemicals for analysis and research work, and the less common chemicals generally may be included under this heading. This is the most highly specialized and to the layman the least known branch of chemical industry, but it is no less essential to industrial prosperity and national safety than those already outlined. The biggest and best known of its activities is the manufacture of dyes, which is important for the manufacture of explosives in that nitration is a process essential to both. It was the ascendency established by Germany in the dye industry, which involved as a *sine qua non* the erection of big nitration plants and the training up of numerous chemical staffs conversant with the methods of manufacture, which gave the enemy so great an advantage in the production of explosives during the earlier years of the war. Inasmuch as sulphuric acid and chlorine, corrosive products difficult to transport, are essential to the fine chemical manufacturer, the two branches of heavy and fine chemical industry are so inter-connected that it is an advantage to be able to carry them out together, and this was generally done in Germany during the last thirty or forty years. It is in this branch especially that the advantages of combination and co-ordination are most apparent, but it would be difficult to make this clear to the non-technical reader without descriptions at great length.

In the above very brief and disconnected account, no mention has been made of the fermentation and distilling industries, of the manufacture of soap, lime and cement, glass, paints, enamels and varnishes, and many other activities in chemical industry, almost all of which have importance for the production of explosives as for other chemical manufactures, but it is hoped that enough has been written to give the reader some rough idea of the extent to which chemistry underlies industrial activities, of the interdependence of its various branches, and of its importance from the point of view of provision in case of war. The healthy life of a modern industrial state is very complex, and depends on the regular and satisfactory working of a great number of factors. Whether any or all of these can best be regulated by some form of control, either by the State or by combination of the interests concerned, or whether the ordinary economic laws can so function as to produce the best results, is in most cases an open question, but so far as chemical activities are concerned, there is no doubt that a wise and broad-minded directorate, working under suitable safeguards, could achieve results which the pre-war competitive conditions could never have brought about.

It must be remembered that the application of chemistry, and of science generally, to industry is only a century old. A century is a short time in the political development of so old and well-established a community as the British nation, and until the needs of the war revealed the complexity of our industrial life, it may be fairly said that no true and comprehensive realization of the weakness and the strength of our interdependent industrial activity had entered into our political system. We are now slowly realising, as a nation, that co-ordination and co-operation are necessary to industrial efficiency, and that they can be secured without much real sacrifice of that individualism which is the special and peculiar characteristic of the English nation. When this realization becomes complete, the services of science will be much more fully at the disposal of the community than they have been in the past. Let us repeat that the scientific application of chemistry to industry is but a century old, a century of individualism old; what may we not hope to accomplish in another century, if co-operation and co-ordination can but reconcile the past divergent and blindly warring interests?

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