Some War Developments of Explosives.[1]

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IT is not proposed to describe the great factories that arose during the war for the manufacture of explosives, but to indicate by one or two examples some of the conditions which led to developments.

PRODUCTION.

The enormous weekly production was reached of 1500 tons of trinitrotoluene, 300 tons of picric acid, 3000 tons of ammonium nitrate, and 2000 tons of cordite. To produce these were required such weekly quantities as the following: 6600 tons of pyrites, or 2700 tons of sulphur, 8300 tons of Chile saltpetre, 720 tons of toluene (from 600,000 tons of coal), 162 tons of phenol (which would have required 1,000,000 tons of coal, if synthetic production had not been established), 700 tons of ammonia (from 250,000 tons of coal), 374 tons of glycerine (from 2700 tons of fat), 700 tons of cotton cellulose (from 1060 tons of wastes), and 1200 tons of alcohol and ether (from 4200 tons of grain).

These numbers indicate not only the magnitude of the production, but also the interdependence of a large number of industrial chemical activities, and, although many of the products were derived from our own coal, it brings home the dependence of the country on overseas transport of many of the essential substances, such as pyrites, sulphur, Chile nitrate, and cotton.

FIRING AND DETONATION OF A SHELL.

The Propellant.—The processes for the manufacture of cordite and of its ingredients had been the subject of study, and considerable advances had been made, so that it might fairly be claimed that this country led the way in the technique and safety precautions involved in the manufacture of propellants. The existing factories were also capable of extension, until the demand became so great that additional ones had to be erected.

At first, the propellant used was cordite M.D., composed of nitroglycerine, guncotton, and mineral jelly, in which acetone was used to gelatinise the guncotton. A nitrocellulose powder obtained from America was also used. The demand for propellant to be made in this country ultimately reached 1500 tons a week, and this, even with an efficient system of acetone recovery, would have involved an expenditure of that solvent of above 400 tons a week. On account of the shortage of supply of this solvent, a new propellant for the Land Service was introduced—cordite R.D.B.—in which ether-alcohol was substituted for acetone as a solvent, a change necessitating the choice of a nitrocellulose of a lower degree of nitration than guncotton, and alterations in the proportions of the other ingredients. For the new propellant the conditions were laid down and met that it should have the same heat energy, that it should give the same ballistics as cordite M.D., in order to avoid alteration in calculating ranges from data obtained with the older propellant, and that it should be capable of being manufactured by the machinery available and with the technique of manufacture known in the country.

The main changes introduced were in the manufacture of the nitrocellulose and in the supply of the solvent. As ether-alcohol is a less powerful solvent than acetone, even for the special nitrocellulose employed, a strict definition of the nitrocellulose was necessary, and the necessity to provide this in suitable form led to much investigative work on the nature of the cellulose, with the result that its manufacture was brought under a system of strict chemical control. This control had among its objects the elimination of ligneous impurities and the standardisation of the viscosity of the cellulose, since if its viscosity were uniform and low, it was found that the gelatinisation of the nitrocellulose when incorporated with the nitroglycerine and mineral jelly was greatly facilitated, and the production of uniform cords assisted. Ligneous matter in the cellulose was rendered visible by a process in which the woody matter was selectively dyed, and the viscosity of the cellulose was measured by the rate of fall of a steel sphere falling through a solution of cellulose.

The supply of alcohol was obtained entirely from the distilleries of this country, and a large plant for converting a portion of it into ether was erected at Gretna. Nearly 1000 tons of alcohol, or the equivalent of about 200,000 gallons of proof spirit, were required for the production of the 1500 tons of R.D.B. cordite a week, and this requirement it was which led to the restricted sale and increased cost of whisky.

THE HIGH EXPLOSIVE SHELL.

Prior to the war the Land Service used for the most part shrapnel shell, designed to project a shower of lead bullets, efficacious against *personnel,* but of little value in attacking fortified positions, for which high explosive shell are required.

Shrapnel was very largely used by the Land Service throughout the war, but the earlier type of high explosive shell filled with lyddite (picric acid), and brought to explosion by the ignition of a fiercely burning mixture, was abandoned for one in which true detonation was secured with certainty. The latest type of high explosive shell was exemplified by a 4·5-in. howitzer shell fitted with a graze fuze (Fig. 1).

The Fuze.—A graze fuze is a mechanism which gives rise to a flash when the shell grazes on

[1] Summary of a Friday evening discourse delivered at the Royal Institution on May 6.

the ground. It must be capable of being handled roughly without firing, and must not act when the considerable forces involved in firing it from a gun are impressed upon it and upon all its parts. The magnitude of these forces is illustrated by the fact that a fuze weighing $2\frac{1}{2}$ lb. when fired from an eighteen-pounder gun weighs about 11 tons—the stress corresponding to 15,000 times the acceleration due to gravity. These forces are taken advantage of to render the fuze "live"—that is, to put it into a condition when it will act on the slightest provocation.

In the interior of the fuze is a brass cylinder with an axial hole, on the top of which is placed a capsule containing a highly sensitive flash composition. To prevent this cylinder from moving forward in handling, a bolt lies athwart its top edge, and this bolt is retained in this position by a small pin placed vertically at the back of the bolt and having its base pressed upward by a spring working in a vertical cylindrical cavity. On firing, this pin, weighing 1·3 grams, is acted on by a force equivalent to 20 kg., overcomes the resistance of its spring, and recedes into its cavity. The force due to the shell's rotation causes the bolt to fly outwards, thus freeing the brass cylinder, which now is prevented from moving forward on to a needle only by the interposition of a light spring. The fuze is now "live," and on the slightest check being given to the forward movement of the shell, as, for example, by grazing on soft earth, the cylinder moves forward by its own inertia on to the needle, which pricks the capsule, causing a jet of flame to pass down the centre of the fuze. The object of all this mechanism is to supply at the proper time a flash for operating the next member, the gaine, where it gives rise to a detonation.

The Gaine.—This is a tube (from French *gaine,* a sheath) with steel walls of quarter-inch annulus. In its upper portion is a pellet of gunpowder which is ignited by the flash from the fuze, and sends a larger flash on to an open capsule containing fulminate of mercury situated over pellets of tetryl. The fulminate detonates, and in turn causes the tetryl to detonate, and to deliver from the bottom end of the gaine a very intense blow to a series of explosive intermediaries which communicate the detonation to the main bursting charge.

Intermediaries.—The first of these is a bag of T.N.T. crystals situated in a thin steel container tube which encloses it and the gaine. This T.N.T., on detonation, brings to detonation an annular layer of T.N.T. cast round the container, and this in turn brings about the detonation of the main charge of the shell. The train of detonation is thus somewhat complicated, and in its evolution many important principles had to be observed.

Sensitiveness and Violence.—Thus the sensitiveness of the various explosives used had to be determined, since, on account of the magnitude of the acceleration imparted to all parts of the shell on firing it from a gun, a column of a sensitive explosive over a certain length and weight will be liable to detonate on account of the sudden force applied. In proportion to their sensitiveness to mechanical shock, therefore, explosives in shell must be graduated in regard to length of column employed. A general principle is to have next to the detonator a somewhat sensitive explosive, and to reinforce the impulse derived from it by one less sensitive, but still delivering an intense blow. It is important, therefore, to have quantitative values for the sensitiveness of explosives to mechanical shock, and some of the values thus obtained are given in the following table:—

	Figure of insensitiveness (Picric acid=100)
Mercury fulminate	10
Nitroglycerine	13
Dry guncotton	23
Tetryl	70
Tetranitroaniline	86
Picric acid	100
Trinitrotoluene	115
Amatol 80/20	120

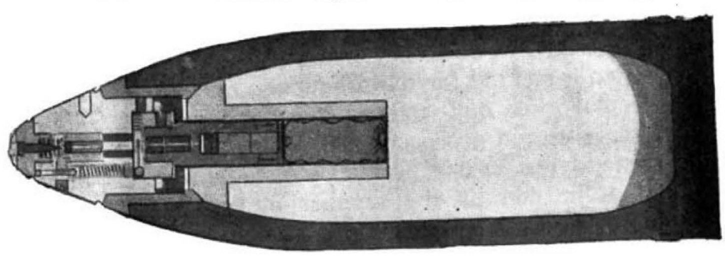

FIG. 1.

It is important also to know the violence of the various explosives used, both by themselves and also when assembled in the various components, and it was in this connection that the principle of the pressure bar, enunciated by the late Prof. Bertram Hopkinson in a discourse to the Royal Institution in January of 1912, was of the greatest value. This depends on the experimental resolution of the momentum of the blow into pressure and time. When a charge is fired against the end of a cylindrical steel bar ballistically suspended, a wave of compression travels along the bar and is reflected at the far end as a wave of tension. To investigate the properties of the wave, a short length of the end of the bar farthest from the end to which the blow is delivered is cut off and the faces are surfaced, the short piece (known as the time-piece) being caused to adhere closely to the bar, usually by a film of vaseline. The compression wave travels unchanged through the joint into the time-piece, but the reflected tension cannot pass through it. Hence when the amplitude of the reflected tension wave reaching the joint becomes greater than that of the oncoming compression wave, the time-piece is projected from the shaft with a momentum which depends on the pressure exerted by the explosive and the time taken by the wave to traverse the length of the time-piece. This momentum is measured by catching the time-piece in a ballistic pendulum, and, the velocity of the propagation of the wave through steel being known, the mean pressure exerted during an extremely small time interval can be calculated.

(One of the instruments for determining the pressure developed by a detonator was shown, and a detonator fired, the mark drawn by the swing of the pendulum which caught the time-piece being shown on the screen.)

The application of this apparatus not only gave important information as to the limiting quantity of fulminate necessary to bring about complete detonation of the tetryl and as to the effect of the thickness of the wall of the gaine, but it also emphasised the necessity for avoiding gaps in the train of detonation on account of the very rapid falling off in violence of the blow when even a small air-gap is introduced.

Main Filling.—It was early recognised that the supply of picric acid and T.N.T. by itself would be quite insufficient. It was at this point that the late Lord Moulton took steps to secure supplies of essential explosives and their ingredients, with such success that the supply of explosives in no long time came to be ahead of the demand. But even when a method for the production of T.N.T. had been worked out, and its supply on a fairly large scale was in prospect, it was apparent that the demand for high explosive was such that it could not be met by the supplies of nitro-compounds in sight.

Experiments were then made to test the capabilities of mixtures of ammonium nitrate and trinitrotoluene for shell filling, and these gave much promise from the start. They were found to possess the requisite degree of inertness and insensitiveness to enable them to withstand set-back on firing from a gun, to have a high rate of detonation, and when detonated in a shell, as was done first in March, 1915, to give evidence of the required violence necessary to fragment the shell.

The first mixture (later termed amatol 40/60, these being the proportions of ammonium nitrate to T.N.T.) was capable of being poured as a thick porridge into shell, and so presented few difficulties for large-scale production. This was at once followed up by similar experiments with a still greater proportion of ammonium nitrate, up to that which is practically the theoretical one for complete combustion of all the carbon of the trinitrotoluene to carbon dioxide, and of all the hydrogen in both substances to water. This explosive, amatol 80/20, was fired in a shell in April, 1915, and gave excellent results. Its explosive properties, as regards insensitiveness, stability, and tests for power, were satisfactory, and it was almost immediately approved as a Service explosive.

Amatol 80/20.—The development of amatol 80/20 was slower. Prepared originally on the large scale by bringing together the finely powdered ingredients in a mixing machine, or by grinding them under edge-runners, 80/20 amatol was ultimately most readily produced by taking advantage of the plasticity of the heated mixture due to the trinitrotoluene melting. Hydraulic presses were used for introducing the powdered or ground explosive into shell; for the plastic 80/20, a worm feed was found expeditious and rapid.

In the course of the manufacture of the enormous quantities of these substances many points of interest and of difficulty arose, which were solved by the assistance of more and more scientific investigators.

The following tables give some data on the explosive properties of the amatols in comparison with some other explosives:—

Heat of Detonation and Gases Evolved.

	Calories per gram (water gaseous)	Total gases c.c. per gram
Picric acid ...	914	744
Trinitrotoluene	924	728
Amatol 40/60 ...	920	892
Amatol 80/20 ...	1004	907
Tetryl	1090	794
Guncotton ...	892	875
Nitroglycerine	1478	713

Rates of Detonation.

	Density of loading	Metres per second
Nitroglycerine ...	(Liquid)	8000
Tetryl	1·63	7520
Guncotton (dry) ...	1·20	7300
Picric acid	1·63	7250
Trinitrotoluene ...	1·57	6950
Amatol 40/60 ...	1·55	6470
Amatol 80/20 ...	1·50	5080

Pressures developed by Ammonium Nitrate, Amatols, and T.N.T.

Ammonium nitrate	Trinitrotoluene	Tons per sq. in. in $0·5 \times 10^{-5}$ sec.
100	0	12·5
99·5	0·5	15·2
99	1	18·3
98	2	20·0
95	5	25·2
90	10	30·5
80	20	38·1
40 (at density 1·55)	60	53·9
0 (at density 1·55)	100	55·0

It will be seen that the addition of 40 per cent. of ammonium nitrate to T.N.T. does not markedly reduce its heat value, rate of detonation, or pressure developed, and that amatol 80/20 has a high content of heat energy, but a rate of detonation and pressure lower than T.N.T. itself. It is, however, still sufficiently violent to fragment shell satisfactorily, and the somewhat slower development of the pressure, together with the high calorific value of the explosive, may be of advantage in enabling the fragments to acquire a higher velocity. It will also be observed that ammonium nitrate itself under a powerful initial impulse gives rise to a notable pressure, so that that ingredient is not to be looked on as a diluent of the T.N.T., but as an explosive substance, as well as a purveyor of the oxygen in which T.N.T. is deficient.

Smoke.—For the purpose of correct ranging and locating the position of burst, an explosive developing smoke is desirable. Amatol 80/20, when used alone, had the disadvantage that it gave no smoke, as the products of the detonation are colourless gases, thus :—

$$2C_7H_3N_3O_6 + 21NH_4NO_3 = 24N_2 + 47H_2O + 14CO_2 ;$$

whereas, when picric acid or trinitrotoluene detonates, a large quantity of unconsumed carbon is set free, affording a black cloud useful for the purpose of observation.

Mixtures capable of producing a white smoke, useful for aerial observation, were then added, and as a result of investigations as to the best method of securing its dissociation, ammonium chloride in conjunction with the ingredients of amatol was localised at the base of the filling.

Needless to say, there were many other developments in explosives practice during the war, but the example of the train of detonation leading up to the complete detonation of a high explosive shell was chosen to exemplify the subject of this discourse, since it included many features and new problems which had an intimate connection with the technical development of the subject.

To secure the high percentage of detonations that our artillerists obtained with the freedom from prematures which they always demanded, it was necessary to have each part of the somewhat complicated train as nearly perfect as possible not only in design, in order to withstand the effects of rough usage and of set-back in the gun, but also in workmanship, both mechanical and chemical as to purity of materials. This was achieved by the co-ordination of a large number of industries organised on a scientific basis, and these were becoming every day more and more efficient. War is now so highly organised that for its successful prosecution all the technical industry of the country is brought under requisition, and to succeed requires a higher development in research, applied methods, and industrial progress than belongs to the enemy.

The effort made by this country in the time of stress to overcome deficiencies in these respects was successful as a great technical achievement, and should be an encouragement to us to look forward to an equal development of our scientific industries under the stress of a competitive peace.

Stellar Parallax.[1]

By SIR FRANK DYSON, F.R.S.

IN the past ten years a number of the large telescopes of the world have been applied to the determination of stellar parallax. The principle of the method is well known and is extremely simple, merely consisting in the detection of the small annual movement of a near star with reference to more distant stars caused by the different position occupied by the observer in consequence of the earth's annual revolution round the sun. The whole difficulty consists in the extreme minuteness of the angle to be measured. If two railway lines, starting at King's Cross, instead of remaining parallel, met at Newcastle the angle between them would be of the order of the angle to be measured in finding the distances of the nearest stars. To form an idea of what is now being done by large telescopes using photographic methods, imagine two plumb-lines 5 ft. apart. They are sensibly parallel, but actually meet at the centre of the earth, and the angle between them is 0·05″. An angle of this size is measured with an accuracy of ±0·01″. Results of this high value were first obtained by Prof. Schlesinger at the Yerkes Observatory. At the present time the observatories of Allegheny, Greenwich, McCormick, Mount Wilson, Yerkes, and a number of others are engaged on a comprehensive programme. At Greenwich we determine the parallaxes of fifty stars a year; at some of the American observatories many more.

Necessarily, a good deal of care is required both in taking the photographs and in measuring them. The image of a star may have a diameter of 2″ or 3″, and the position of its centre should be measurable to between 1/50th and 1/100th of this amount. The methods of measurement present some points of interest which need not be described now, but a word or two about the precautions to be observed in taking the photographs may be of interest. The images must be as circular and uniform as possible. (1) The guiding of the telescope must be as perfect as possible. (2) The lenses of large object-glasses must be adjusted with great care so that there may be neither tilt nor eccentricity between them. (3) Photographs should all be taken with the telescope pointing in the same direction. One cannot be taken when the field is east and another when it is west. Atmospheric dispersion and possibly minute flexure of the lenses cause slight deformation of the images which may be scarcely visible to the eye, but appear in measures. (4) The star the parallax of which is being determined and the comparison stars should have approximately

[1] From a discourse delivered at the Royal Institution on Friday, April 29.