

SECT. II.—OTHER SELECTED PAPERS.

(Paper No. 3144.)

“Some Properties of Cordite.”

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CORDITE¹ is an intimate mixture of 58 per cent. of nitro-glycerine, 37 per cent. of gun-cotton, 5 per cent. of vaseline, and probably a trace of non-volatile impurities associated with the acetone, about 20 per cent. of which is used to facilitate the intimate blending of the nitro-glycerine and gun-cotton.

Nitro-glycerine ($C_3H_5N_3O_9$) is a light yellow oily liquid, having a specific gravity of about 1·6; it is inodorous and has a sweet, pungent, aromatic taste. Contact with it or the inhalation of its vapour is apt to produce violent headache in those who are not accustomed to it, but the effect diminishes by degrees; and men who are constantly employed in connection with it after a time suffer no inconvenience. The constituents of nitro-glycerine are in an unstable condition and capable of re-arrangement. Two molecules, on explosion, are converted into $6(CO_2) + 5(H_2O) + NO + N_5$, from which it will be seen that there is sufficient oxygen to completely oxidize the hydrogen and carbon, and that consequently no CO is produced. Decomposition takes place spontaneously at about 160° C., and detonation at 257° C., or with great violence from local application of heat or from concussion. So dangerous is the substance that its transport is absolutely forbidden. The manufacture of nitro-glycerine is a service of considerable danger unless carried out with the most scrupulous care, but under proper regulations rigorously enforced it is, on account of the absence of dust, not so dangerous as the manufacture of black or brown powders. The effect of the explosion of even very large quantities is by no means so far-reaching as is popularly supposed. In May, 1894, there was, at Waltham Abbey, an explosion of nearly $1\frac{3}{4}$ ton (3,700 lbs.) of nitro-glycerine; little or no injury resulted to the town. The radius within which appreciable damage was caused did not exceed 900 yards, while

¹ See also “The Machinery used in the manufacture of Cordite,” Minutes of Proceedings, Inst. C.E., vol. cxxxii. p. 69.

serious injury was only experienced within 95 yards. A considerable quantity of nitro-glycerine, which was in a building immediately adjoining one of the two in which the explosion occurred, was not detonated, debris fell within a radius of 700 yards, and a few windows were broken at a distance of $2\frac{1}{2}$ miles. It will be seen from this example how vain and foolish is the idea of laying towns in ruins and destroying fleets and armies by means of nitro-glycerine or explosives with fantastical names derived from it.

Gun-cotton has been familiar to artillerymen for many years, and that known as Abel's gun-cotton is universally used as a violent explosive for war purposes. Its chemical composition is $C_6H_7O_2N_3O_9$, and on combustion these elements rearrange themselves as follows— $5 CO_2 + CO + H_7 + N_3$, from which it will be seen that there is not sufficient oxygen to ensure complete combustion of the carbon, and this gives rise to a considerable evolution of CO, a poisonous gas which makes its presence felt, when even in small quantities, by causing nausea and headache. When gelatinized gun-cotton is used alone for the charges of heavy guns, the inconvenience described is considerable. The gun-cotton used in making cordite is precisely the same as the service explosive which has been used for so many years in mines and torpedoes, except that no alkali or disinfectant is added as a preservative to the pure article. At Waltham Abbey the gun-cotton pulp intended to be made into cordite is lightly pressed into the form of cylinders 3 inches in diameter and $4\frac{1}{2}$ inches high, containing 9 ounces of the dry material. These cylinders or disks are dried in stoves fitted with light wooden trays having perforated bottoms, each tray holding forty-eight disks. The trays are placed in racks and subjected for about a week to currents of air heated by steam tubular heaters to 100° F. The drying is continued till the moisture is reduced to about $\frac{1}{2}$ per cent. The manufacture of gun-cotton is a perfectly safe operation up to the point where the moisture is reduced below 10 per cent. in the stoves, but then, on account of the light dust, the formation of which it is impossible altogether to avoid, extreme care in the manipulation has to be observed. Formerly the damp gun-cotton was spread as a loose pulp on the trays, but the quantity of dust formed was so great that the present system of moulding the pulp into cylinders was adopted. No one is allowed to enter the stoves while the drying is in progress, except for the purpose of taking samples. When the material is dry and ready for removal, the stoves are allowed to cool, and then the trays are not moved in any way, but the cylinders are carefully transferred by hand from the trays to

special boxes. The men employed enter with bare feet or wearing only clean socks, the stoves are carefully swept out after each unloading, and are thoroughly washed after every four stovings. At one time the dry gun-cotton was moved into a special store, but, in order to reduce the risks arising from removal as much as possible, the stoves themselves are now treated as stores till the contents have been gradually removed in accordance with the exigencies of manufacture.

In March, 1893, one of the stoves at Waltham Abbey caught fire spontaneously. The wet charge, consisting of 4,212 lbs. of dry gun-cotton, was inserted on the 24th February, and at 6.30 A.M. on 2nd March the attendant examined the thermometers, which could be read without entering the stove, and found them at about 102° F. The stove was to have been emptied that morning, consequently the material was judged to be perfectly dry; but at 7.25 A.M. a bright flame was seen to shoot into the air accompanied by a loud roar, but by nothing in the nature of an explosion. The light circular wooden building, 30 feet in diameter and 10 feet high to the eaves, situated within a strong circular traverse, had its light roof blown off, the woodwork was set on fire, and the intense heat melted most of the lead and copper work, but the traverse which surrounded the stove within a couple of feet of its walls, and even the doors in the tunnel leading through it, were uninjured; in fact the latter had to be unlocked to admit the firemen. As is usual in such cases, no cause could be assigned for the fire; the probable origin lay in the spontaneous combustion of gun-cotton dust collected on the copper heating-pipes, which, at that time, were inside the stove, so that the dust could settle on them. They were, indeed, protected by lagging of non-conducting materials, but it is difficult to believe that the protection was so complete that dust could not make its way to the bare metal, and although the temperature of this did not exceed 120° F., yet even that would in time cause decomposition of substances much less sensitive than gun-cotton. It is well known that insurance companies will not allow hot-water pipes, the temperature of which is generally below 160° F., to be laid in contact with ordinary woodwork, on account of the risk of spontaneous ignition arising from the slow decomposition or charring of the wood. The hot-air pipes are now arranged outside the stoves, and entrances for the hot air are provided all round by means of branches entering through the walls.

Although the fire at Waltham Abbey led to no explosion or loss of life, a similar occurrence at Arklow, in October, 1895, had very

different consequences. There a stove, measuring 20 feet by 14 feet, was charged with only 275 lbs. of dry gun-cotton, and this exploded violently while a man was manipulating it. The man and stove were blown to pieces, and considerable mischief was caused all round the site. In this case the gun-cotton was in the form of a loose flocculent mass, the workmen wore magazine shoes, and the stove was cold; 25 lbs. of damp gun-cotton, which was in a box on the floor, was not exploded, though it was scattered in all directions. The difference of effect in the two cases cited is very curious, and seems to point to the necessity of drying gun-cotton in the form of compact masses capable of retarding the rapidity of burning, and to the adoption of other precautions prevailing at the Government factory.

The dry gun-cotton is placed, in weighed charges, into brass-lined wooden boxes, and taken to the mixing-room, which also contains the finished nitro-glycerine, which is made in lots of about 700 lbs. The vat containing the nitro-glycerine is placed sufficiently high to allow of drawing it off into gutta-percha jugs placed upon a weighing-machine. Earthenware taps are used, the greatest care is exercised to wipe up every drop that may adhere to the pipes or the jugs, and the movements of the men are slow and deliberate. The weighed charge of nitro-glycerine is then poured over the gun-cotton, and carefully mixed with it by the bare hands of the men. It becomes completely absorbed, and the mass, now called "paste," assumes the appearance of light-brown moist sugar, and, curiously, becomes perfectly safe, that is to say, it will not explode when in moderate quantities, though it burns fiercely. In this condition it is quite safe to transport in regulation packages consisting of waterproof india-rubber bags packed into small barrels. The Government factory supplements its own supply of nitro-glycerine by sending wet gun-cotton to several private factories, and receiving it back in the form of "paste," that is, mixed with nitro-glycerine. It was due to this property that the disastrous explosion to which allusion has been made, and which completely wrecked the nitro-glycerine plant at Waltham Abbey, scarcely interfered with the production of cordite.

The "paste" is next placed into kneading machines, together with about 20 per cent. of acetone, and incorporated for $3\frac{1}{2}$ hours, when 5 per cent. of vaseline, or mineral jelly, is added, and the kneading carried on for another $3\frac{1}{2}$ hours. Acetone acts as a solvent both of the nitro-glycerine and the gun-cotton, and on that account promotes the intimate mixture of the two. It is all

evaporated during the subsequent processes, and forms, therefore, no part of the finished cordite.

The "dough," as it is called, when thoroughly incorporated, is placed into iron or brass cylinders of various sizes, depending on the diameter of the cords to be produced, and pressed by means of closely-fitting pistons, impelled by hydraulic or screw power, through a die or dies arranged in the bottoms of the cylinders. The dies are really nozzles of diameters and lengths which experience has shown to be suitable for producing the size of cord required. With all the care that is taken to keep the manufacture absolutely clean, it is found impossible to prevent dirt getting in, hence the bottoms of the cylinders are fitted with wire-gauze strainers, through which the dough is pressed before it reaches the nozzles. Occasionally slight explosions occur in the cylinders; their origin is obscure, as many thousand charges are dealt with without accident, but a small portion of a charge sometimes ignites and an explosion more or less violent takes place. Sometimes the force is sufficient to destroy the cylinder and otherwise injure the presses; but, in every instance that has occurred only a very small fraction of the charge has ignited, the bulk of it has remained quite unaffected though possibly scattered about the room. The cords vary in diameter between 0.01 inch and 0.65 inch. The former is used for chopping into pistol ammunition, the latter for the new 12-inch wire gun. The cords for filling into small-arm cartridges are wound on reels holding about 1 lb., on which they are stoved at about 100° F. till the material ceases to lose weight. The larger cords are cut into lengths suited for the cartridges into which they are to be made up, and arranged in thin layers on wooden trays, in which they are stoved in the same way as the reels. In order to insure the greatest possible uniformity, the cords, when thoroughly dry, are blended by carefully mixing a large quantity together. The finished blended cords are then packed in boxes holding between 70 lbs. and 100 lbs. each, and every 10,000 lbs. is called a "lot."

Cordite may be squirted into strands of any shape, but the solid cylindrical form has been found most convenient. A small quantity is made into pipes about 1 inch in diameter by 4 inches long to hold the powder priming of cannon cartridges, to which allusion will be made later. Owing to the compact horny nature of cordite it burns only on the surface, the rapidity of combustion depending on the proportion of surface to volume, on the pressure and temperature in the chamber of the gun. So

remarkably even is the combustion that cord which is sometimes thrown out of guns only partially consumed retains all its original proportions; the cords are shorter and thinner, but they are truly and evenly cylindrical, even when reduced to the substance of a hair. Cordite can be exploded by concussion, but the explosion is confined to the part contused; the fire is not communicated to the free portions on each side. When not confined in a strong chamber it cannot be exploded even by a detonator; it burns with great fierceness, but without any report.

An experiment was made at the Royal Arsenal, Woolwich, of building eight boxes, containing 100 lbs. of cordite each, into a bonfire. As the boxes burned away and exposed the contents or raised them to the temperature of ignition they flared off one after another, and in most cases the lids of the boxes were not blown off, but merely forced open enough to allow the gases to escape. In order to ascertain the degree of danger to be apprehended in drying cordite, a stove 19 feet 6 inches by 12 feet 6 inches, capable of holding 2,500 lbs. laid out on wooden trays, was built. The walls were of 14-inch brickwork, the roof was of slate; there was a small window in each gable, and a door in one side. The stove was kept at a temperature of 100° for 9 days, and the contents were then set on fire. A vast body of flame was seen to shoot up, the roof was lifted off and deposited, almost uninjured, beside the house, the gable windows were unbroken, and the door was intact and had to be unlocked to admit the firemen to extinguish the burning woodwork.

It does not follow from these experiments that an explosion would not result if several hundred tons of cordite, stored in a magazine, were to catch fire, but it indicates the safety from small explosions which are so disastrous with black powder. If subdivided sufficiently and packed lightly into strong metal cases it will detonate with great violence, and on that account the boxes in which cordite is stored are made as light as possible, consistent with strength. Experiments also made by firing at the limbers of field-guns show that no explosion of cordite charges carried in them is to be apprehended. Notwithstanding these advantages there has been no relaxation in favour of cordite of the rules which apply to explosives.

The ballistic power of cordite is very nearly four times as great as that of black powder; thus 1 lb. of cordite fired in the 3-inch 12-pounder field-gun produces the same effect as 4 lbs. of selected pebble-powder which used to be the service charge. The cause of this superiority is two-fold. In the first place, only 43 per cent.

of black powder is operative, that is, produces gas; the remaining 57 per cent. is composed of inert matter, which not only does not add to the propelling power of the gases, but absorbs some portion of their energy in having to be heated and propelled itself. Thus, in the field-gun, which carries a shot of $12\frac{1}{2}$ lbs., of the 4 lbs. of powder burnt a little over $2\frac{1}{4}$ lbs. are inert, and might as well form part of the shot, so that virtually $1\frac{3}{4}$ lb. of gases expels $14\frac{3}{4}$ lbs. of projectile and inert matter. On the other hand, the products of the explosion of cordite are nearly all gaseous and effective. One gram of pebble-powder yields 276 cubic centimetres of gas, while the same weight of cordite gives 664 cubic centimetres, supposing, in both cases, the water produced to be in the liquid state, but, as the 276 cubic centimetres of powder gases weigh only 0.43 gram, it follows that 1 gram of the gas-producing part of the pebble-powder yields 642 cubic centimetres of gas, and is therefore nearly as efficient as the cordite, were it not handicapped by the inert matter associated with it. In the second place, the combustion of 1 gram of pebble-powder yields 714 gram-degrees of heat, while 1 gram of cordite produces 1,225 gram-degrees, which are all expended in heating only efficient gaseous matter, while in the pebble it has also to heat the inert portion; hence the temperature of the gases evolved by the combustion of cordite is much higher, and their tension, at the same density of charge, is much increased. The superior propelling power of cordite, it will thus be seen, is the result of the greater specific volume of gases evolved and their much higher temperature.

Solid cordite has a specific gravity of 1.56, and its volume is therefore 17.77 cubic inches to the lb., and if fired at that density would produce a pressure of more than 120 tons per square inch, whereas the greatest pressure that can be attained with black powder is 43 tons per square inch. Under these circumstances it is imperative to make the gravimetric density of the charge, or the number of cubic inches of chamber capacity to the lb. of explosive sufficiently large to render excessive pressure impossible. Cordite made up into bundles measures about 25 cubic inches to the lb., so that a chamber filled with cords might still yield 112 tons pressure. In the magazine rifle the density is 41 cubic inches to the lb., which might give 68 tons pressure; but in cannon the spacing is now limited, when practicable, to 80 cubic inches to the lb., which cannot give a higher pressure than 30 tons. The pressures named are based on the supposition that no heat is lost in warming the gun and projectile, and that the shot has not begun

to move before the combustion has been completed. The gun, however, robs the gases of a good deal of heat, the rate of cooling varying roughly inversely as the calibre, and the diameter of the cords is so proportioned that the burning occupies nearly the same time as that taken by the shot in traversing the bore; the maximum possible pressure can therefore never arise, so that densities between 41 and 80 cubic inches to the lb., of suitable sized cordite, are found in practice to be safe. It is apparent, therefore, that the speed with which the shot starts into motion has an important bearing on the pressures in the chamber. If a series of guns of various calibres were constructed with all their dimensions in proportion to the diameter of the respective bores, and in all the shot were impelled by the same initial pressure, then, because the area of the base of the shot, on which the pressure acts, varies as the square of the diameter, while the weight of the shot changes as the cube, it follows that the impelling or accelerating force per lb. of shot varies inversely as the diameter of the bore. The length of the chase, or the space through which the acceleration takes effect, however, increases as the diameter, and therefore the time in which the muzzle velocity is attained is increased in the same proportion, and the velocity is consequently obtained with smaller relative pressures per lb.

This statement will be rendered clearer if the 3-inch field-gun is compared with the 12-inch wire gun. The initial working pressure generally aimed at is 16 tons per square inch; hence the pressure on the base of the 3-inch shot, which weighs $12\frac{1}{2}$ lbs., will be 112 tons, or 9 tons per 1 lb. of shot. In the 12-inch gun the pressure against the base is 1,808 tons, and as the shot weighs 850 lbs., the pressure per 1 lb. is only 2.1 tons, therefore the speed at which the larger shot will start into motion will be about a quarter of that of the smaller shot; and hence, if cordite of a diameter suitable for the small gun were used, the high proportion of surface to volume would cause gas to be evolved at an excessive rate compared with the rate of enlargement of the chamber due to the motion of the shot, and the result would be high pressure. It is hence apparent why it is so important to select the diameter of cord suited to the nature of the gun, and in practice very minute alterations in diameter are found to produce corresponding changes in ballistics. The cords for the 3-inch or 12-pounder field-gun are 0.05 inch diameter, and for the 12-inch gun 0.5 inch, or ten times as great.

When the capacity of the chamber is very great, over 100 cubic inches to the lb., as commonly happens when cordite is adapted to

the guns made for black powder without any increase to ballistics, then greater latitude may be allowed in the diameter of cords, because the large initial volume of the chamber will prevent the pressure rising beyond 24 tons per square inch, however rapid the burning may be.

Cordite in bundles occupies approximately the same volume as black powder; but because it is four times as efficient, a chamber of one quarter the capacity needed for black powder would hold it, but as about three and a quarter times this volume of air spacing is desirable, the chamber may be about three-quarters of that required for powder to give the same ballistics. The chamber, however, is not nearly filled by the cordite; the bundles of it therefore may be made so small in diameter as to require no greater opening to pass through than that necessary for the shot, hence the great advantages gained of the breech opening not needing to be larger in diameter than that required for the shot, and the practical benefit may be seen in the 12-inch wire cordite gun, which has a breech-block no larger or heavier than that of the 9·2-inch service gun; and it becomes possible to obtain much higher service energies without making the guns inconveniently heavy and bulky. The new 12-inch naval wire cordite gun (mark VIII) weighs only 46 tons, but it has the same penetrating power as the 13½-inch prism powder 67-ton gun.

Cordite, as regards the ballistics it produces, is sensitive to changes of temperature. This, indeed, does not affect the shooting under service conditions, but is often troublesome to manufacturers who have to work within very narrow limits of velocities and pressures. Thus the cordite used in the 12-inch wire gun has to produce a mean velocity of 2,375 feet per second, with the limits plus or minus of 25 feet only, while the pressures must not exceed 17 tons per square inch. To produce such results extreme care must be taken to make the cords of the correct diameter, as a few thousandths of an inch may throw the pressures and velocities up or down. If proofs have to be taken at temperatures varying much from the normal, namely, 60° F. atmospheric temperature and 80° F. of the charge, corrections founded partly on the behaviour of standard lots and partly on empirical rules have to be adopted. To produce cord of any exact diameter is not an easy task, because the material shrinks much in drying and loses weight also by the evaporation of the acetone, but nevertheless experience and careful manipulation enable fairly uniform results to be arrived at.

Because, with the exception of about 5 per cent. of vaseline, the products of combustion of cordite are all gaseous, it is possible,

by determining the necessary constants, to calculate by purely theoretical methods, the work done on the projectile. The following assumptions have, however, to be made: (1) that the charge is completely consumed before the projectile starts; (2) that the gases do no work in expanding to fill the chamber; and (3), that while the gases are expanding and doing work on the projectile, they do so adiabatically, *i.e.*, without imparting heat to the walls of the gun. Neither of the assumptions is correct; but the discharge of a gun takes place in so small a fraction of a second that the error incurred cannot be great.

The following data have been determined by direct experiment :

Atmospheric pressure	= 2,116 lbs. per square foot.
Volume of products of combustion of 1 lb. } of cordite at atmospheric temperature } of 32° F. (or 491·16° absolute) . . }	= 14·021 cubic feet.
Temperature of explosion	= 6,532·3° F. absolute.
Estimated specific heat of gases at con- } stant volume }	= 0·34.
$\gamma = \frac{\text{specific heat at constant pressure}}{\text{specific heat at constant volume}} .$	= 1·23
Heat evolved by exploding 1 lb. of } cordite and expanding to atmospheric } pressure and 32° F. temperature . . }	= 2,054 B.T.U.

With the exception of the specific heat of the gases these data have been determined by direct experiment by Dr. Kellner, Chemist to the War Department. The specific heat of gases at the enormous temperatures and pressures which exist in cannon cannot be arrived at except by means extremely costly, even if then. It has been assumed, therefore, that the value ascertained by Messrs. R. Mallard and Le Chatelier for very hot furnace-gases at atmospheric pressure will hold, and certainly, the closeness of agreement between the calculated muzzle-energies and those obtained by direct measurement in firing guns seem to justify the assumption.

A gun may be regarded as an engine cylinder which gives one stroke of its piston when fired, and therefore the degree of expansion at which it works is an element in the calculations of the power developed. In modern guns the ratio which the volume of the powder chamber bears to the total volume of the bore of the gun is about one-fourth, so that the gases in the gun expand fourfold. In the British service, however, as will be seen by the annexed Table, this figure varies greatly because of the number of guns, originally made to consume black powder, having been converted to cordite guns. There are strenuous advocates for the use of much higher initial pressure than the modest 16 tons or 17 tons

which forms the limit in use in Her Majesty's Service, but such advocates confine their attention to the possibility of making a safe gun, say, for 30 tons pressure, and quite lose sight of the strength of the walls of shells necessary to stand such pressures, and the consequent reduction of burster. They also ignore the delicate mechanisms of the lock and firing-tube and of the base and nose fuses. It is easy enough to make the gun, but by no means so to make its fittings.

Having determined the proportions of a gun it is only necessary to apply the well-known formula for work done in adiabatic expansion to obtain the energy imparted to the shot, and thence its muzzle-velocity, if this be needed. The following Table gives a list of eight cordite guns in which the calculated and observed muzzle-energies are compared :—

Gun.	Ratio of Volume of Chamber to Total Volume of Bore.	Weight of Cordite Charge.	Muzzle Velocity.	Chamber Pressure.	Muzzle-Energy.		Ratio of Actual to Calculated Muzzle Energy.
					Actual.	Calculated.	
		Lbs.	Foot-Secs.	Tons.	Ft.-Tons.	Ft.-Tons.	
12-inch wire . .	0·2555	167·5	2,361	16·00	32,850	34,585	0·95
9·2-inch wire . .	0·2512	94·5	2,674	17·13	18,860	19,700	0·96
8-inch service . .	0·2487	32·6	2,150	13·81	6,731	6,843	0·98
6-inch service . .	0·2685	14·75	1,960	12·1	2,664	2,948	0·90
6-inch quick-firing .	0·1094	13·25	2,154	12·95	3,217	4,127	0·78
4·7-inch quick-firing	0·0858	5·44	2,150	14·0	1,442	1,797	0·80
4-inch service . .	0·1075	3·56	2,342	14·5	94,512	1,094	0·86
3-inch 12-cwt. . .	0·1874	15·00	2,280	13·6	450·5	543·8	0·83

It will be observed that the efficiency of the guns, *i.e.* the ratio between the calculated and the observed muzzle-energies decreases with the decrease of calibre and increase of expansion. This is to be expected, on account of the relatively high cooling power of the smaller guns.

As regards the stability of cordite under various climatic conditions, extensive experiments have been made, not only at the Arsenal in a hut where it has been kept for a long time under various extremes of temperature and moisture artificially produced, but under natural conditions in the heats of India and the extreme cold of a Canadian and an arctic winter. No difference in ballistics of any practical consequence has been observed, and when chemical tests have indicated some slight change the explosive appears to regain its normal properties when restored to normal conditions.

As stated in the opening paragraph, cordite is but a mechanical

mixture of the ingredients of which it is composed; hence the nitro-glycerine, which, like all liquids, is volatile, will gradually escape if the cordite be freely exposed, but when kept in the proper manner in service cases no appreciable change has been detected during the time it has, up to the present, been stored. In prolonged cold weather the nitro-glycerine sometimes exudes a little and renders the surface of the cords damp, but it is again absorbed as soon as the material becomes thoroughly warm. Exhaustive experiments have proved that no danger arises from the exudation, and that the ballistics are unaffected.

The action of cordite on the bore of guns is universally supposed to be much more serious than the wear produced by black powder. The Author is at a loss to conjecture how such opinions have arisen. The comparison is not easy to establish, because, as a rule, guns firing cordite have much higher ballistics than those using black powder. For example, the new 12-inch gun imparts to its 850-lb. shot nearly twice the energy which the old service gun communicated to its 714-lb. shot; hence, if the new cordite gun were to wear more quickly it would be no proof that the effect was due to the explosive. The wear produced by cordite is of a totally different character to that resulting from black powder. The latter eats into and scores the surface of the bore in a remarkable manner, obliterating the rifling and allowing very great windage, especially in the upper part of the bore. This is probably due to the mass of inert solid or liquid matter rushing past the shot, and, in so doing, rasping out the steel. In the case of cordite, the surface of the bore seems to be dissolved and washed away by the exceedingly hot gases, the effect being greatest close to the seat of the shot, and dying away in five or six calibres. The washed-out part is comparatively smooth and free from scoring, the rifling is not obliterated, though a good deal levelled down, but the wear is so favourable that, by fitting the shot with special driving bands provided with obturating rings formed like U leathers, the sealing of the bore, the maintenance of the proper initial position of the shot, and its correct rotation are secured. When the surface of the bore of a worn gun is carefully examined, it is seen that the effect of the hot gases evolved both by the black powder and cordite is to produce a network of fine longitudinal and transverse cracks, especially in the vicinity of the chamber. In the smaller natures, the reticulations so produced are very regular, and measure between $\frac{1}{16}$ inch and $\frac{3}{16}$ inch in the side, while in the 11-inch powder-proof gun the meshes vary between $\frac{1}{8}$ inch and 1 inch in the side, but the larger squares are not so well defined

as the smaller. It would seem as if the frequent and violent compression of the metal caused by the pressure of the powder gases, assisted by the expansion due to rapid heating, probably to about the critical temperature of steel, had the effect of crushing the material, while the sudden release and cooling at the conclusion of the discharge caused a reaction or resilience which produced the cracks. The larger the gun, the deeper the fissures appear to be, and it would seem as if the rush of gas occasionally broke out squares of steel, and afterwards polished the cavities so formed.

The Author had an opportunity of comparing the wear of two 4·7-inch quick-firing guns, one of which had fired 1,039 rounds of black powder, and the other 1,219 rounds of cordite; the velocity in the former gun was 1,781 foot-seconds, and that of the latter 2,189 foot-seconds, and as the energies imparted to the shot vary as the squares of the velocities, it follows that the cordite gun develops 51 per cent. more work than the other, yet the powder gun was deeply scored and eroded, while the other retained its smoothness and even a good deal of the rifling, though the bore near the chamber is considerably enlarged, though not more than that of the powder gun. The Author's belief is that the endurance of cordite guns will be found to be considerably greater than that of those using black powder, in spite of their increased ballistics.

Cordite is unaffected by water, whether fresh or salt. Samples were submerged at Shoeburyness for a considerable time, a portion was then merely dried, another was washed in fresh water and dried, while a third was fired wet. The first two gave normal ballistics; the last showed, as might be expected, a slight falling off due to the evaporation of the water. A barge loaded with cordite was recently accidentally sunk off the Woolwich Arsenal. The cargo lay submerged for a tide; it was then recovered, and the boxes of wet cordite were sent to Waltham, where, in about a month after the accident, the contents were washed, dried, and re-issued to the service after satisfactory proof.

The combustion of cordite yields about 34 per cent. of carbonic oxide gas, and though this is undoubtedly a poisonous substance, no inconvenience whatever has been experienced from its presence. It is also an inflammable gas, and under favourable conditions of wind, cases are not uncommon when, in opening the breech immediately after firing, a tongue of flame issues to the rear. The drill is specially arranged to meet this circumstance, so that no inconvenience arises in practice, neither is there any danger to the next charge in breech-loading guns, because by the time the shot is rammed home all flame has disappeared, and even if the

cartridge which follows the shot were to catch fire, it would not explode like black powder, but simply burn away unless there had been time to close the breech, which would be very unlikely.

One of the difficulties which beset the introduction of cordite was the ignition of the charge. It is most important, especially for naval guns, that there should be no hang-fires, that is, that the charge shall go off the moment the tube is fired. Cordite by itself cannot be ignited by the ordinary tubes, and a priming of some kind is necessary. Dry gun-cotton acts very well, but is objectionable on account of its dangerous nature. Fine-grain powder, however, answers every purpose, and has also the advantage of making a little smoke which, with that produced by the vaseline, helps to lubricate the bore. In ordinary cannon cartridges, with axial ignition, the priming is applied in the form of a pad of red shalloon, filled with about 8 oz. of powder, for the larger natures, and secured to the end of the charge. In quick-firing guns it is of the greatest consequence that there should be no residue from the cartridges left in the bore, as that would interfere with rapid loading; the priming of $1\frac{1}{4}$ oz. is therefore placed in thin shalloon bags inside tubes, made of cordite, built into the cartridge, the whole being contained in the brass quick-firing cases. In small arms, where the cords forming the charge are very fine, only 0.0375 inch diameter, all that is required is a somewhat stronger cap filled with a composition which gives a long flame. In the case of guns having radial vents the priming is placed as a band round the cartridge, so as always to come under the vent, however the charge may be inserted.

All the more important qualities of cordite have now been touched upon, and although it is possible that smokeless powders, composed of gelatinized gun-cotton alone or mixed with various mineral ingredients, may be equally good, there can be no doubt that cordite is, weight for weight, more efficient, and therefore makes up into lighter cartridges. It produces much less of the poisonous carbonic-oxide gas, and, in addition, it is much cheaper.

Like every other new warlike store it has been attacked with considerable virulence, but it is surviving these onslaughts and growing in favour with those who have to use it, and who are responsible for the defence of the country. About seven years' experience has now been obtained with it, and it can be safely asserted that cordite is permanent, safe and trustworthy under all the varied conditions under which it has to be used in the British Empire.