REVIEW.

ON THE DEVELOPMENT OF SMOKELESS POWDER.[1]

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To intelligently present a sketch of what has been done in the development of smokeless powder, it is necessary to first briefly review the history of black gunpowder. Although the place and date of its origin and the name of its inventor are yet open to dispute, it is generally accepted that it was employed as a propellent in cannon at the battle of Crécy in 1346, and in small arms for some time prior to this date, and that it then consisted of a mixture of niter, charcoal and sulphur. Considering the existing state of chemistry, it is fair to infer that the making of gunpowder, like the manufacture of guns, was for long an empiric art, and that, notwithstanding that Tartaglia, Galileo, Newton, Huygens, and many others speculated upon and discussed the effects which gunpowder produced upon projectiles; that granulating was employed in 1445; that Cellini had observed the necessity of adapting the grains to the piece; that sizing was practised in France in 1525, and that Hawksbee had in 1702 measured the volume of gas resulting from a known volume of gunpowder, the science of gunnery had no existence until Robins devised the ballistic pendulum by which he measured the velocity of projectiles and with which he obtained the experimental data upon which his "New Principles of Gunnery," printed in 1742, was founded. The science of exterior ballistic was materially improved when Hutton, in 1778, extended Robins' principle to the use of the gun as the pendulum also, for it became then possible to not only measure the velocity of the projectile, but the energy involved in the reaction, and this method was employed for larger and larger calibers until it reached its practical limit in the very elaborate and precise series of experiments made at the arsenal in this city (Washington) from 1842 to 1847, by Major Mordecai, who succeeded in swinging cannon weighing about 7,700 pounds and throwing 32-pound balls; but this necessitated the use of a pendulum weighing over 9,300 pounds, the center of gravity of which was over fourteen feet below the axis of suspension. The weight and length of the pendulum increases so rapidly with the increase of the projectile that to determine by this method the velocity of the projectile from a 100-ton gun, would require towers like those from which the Brooklyn bridge is suspended, between which to swing the pendulum.

[1] Presidential addrees delivered before the Washington Section of the American Chemical Society, Feb. 21, 1896.

Opportunely as this limit was approached, Dr. Joseph Henry announced, in 1843, his invention of a method for the determination of velocities by interposing screens, which were electrically connected with chronographs, in the path of a projectile and at definitely determined distances from the gun, and this method, which while possessing the merit of great simplicity, is at the same time very precise and capable of being used for determining the velocities of projectiles from guns of every calibre, is now universally employed with chronographs, such as the Boulengé, Schultz-Deprez, and Mahieu, while the principle has been extended by Captain Noble to the study of interior ballistics, in his very ingenious chronoscope by which the velocity of the projectile can be determined at frequent intervals, even when it is moving through the bore of the gun.

The ability to measure the velocities which it produced led to active investigations into the properties of gunpowder and resulted in the experiments of Lavoisier, between 1777 and 1778 on the deflagration of powder, of Berthollet, on the best proportions for mixing the ingredients, of Gay Lussac, on the refining of niter, of Violette, on the production, composition and properties of charcoal, of Gay Lussac and Chevreul, of Bunsen and Schischkoff, of Linck, and of Károyli, on the composition and volume of the products of the combustion of this substance, and of many other experimenters on the effects resulting from differences in the density, hardness, size of grain and other physical characteristics of the explosive. But notwithstanding the great advance made through the invention of methods by which to measure the velocity of the projectile and the recoil of the piece, the science of gunnery was still incomplete without an accurate knowledge of what was going on within the chamber and particularly what pressures were produced and how this pressure was distributed within the gun before the projectile left its seat and while it was traveling through the chase; yet, although direct experimental determinations of the pressure exerted by fired gunpowder were made by Count Rumford in 1797 in a somewhat rude device, and numerous indirect estimations were deduced from the observations of Robins on the volume of the gases produced by its combustion and from the more precise and detailed researches of Bunsen and Schischkoff and the other experimenters previously referred to, no practical means were at command by which to make direct measurements of the pressure developed within the gun itself until Captain Rodman, in 1857, invented the pressure gauge, described in his "Reports of Experiments," published in Boston, in 1861, which in common with several modifications of it, such as the Noble crusher gauge and the Woodbridge spiral gauge, came into general use in all experimental firing and in the proving of guns and powders.

In estimating the pressure developed by powder from the data obtained in their chemical analyses of its products, Bunsen and Schischkoff proceeded on the assumption that Piobert's conclusion from his experiments, *viz.*, "that the rate of combustion of powder is not affected to any sensible degree by heat or pressure," was correct; but their conclusions having been questioned by many authorities, among them by Vignotti, in 1861, and by Craig about the same time, who showed that the products of combustion differs with the pressure, and their physical data by F. A. P. Barnard, who submitted them to a reinvestigation in 1863, and arrived at a widely different result; and they having also failed of verification by the pressure gauge, the matter was again experimentally attacked by Noble and Abel, who employed as a firing chamber a hermetically closed steel cylinder sufficiently strong to resist rupture by the explosion of a charge of powder which completely filled it (such as Dr. Woodbridge had previously used at the Washington navy yard in 1856), in which pressure gauges were enclosed, and they fired the charge by the electric method invented by Dr. Robert Hare in 1832. In addition the apparatus was so contrived that the gaseous and solid products could be collected, measured and analyzed at will.

With this they found that when powder is fired in a confined space the products of combustion are about fifty-seven per cent. by weight of ultimately solid matter, and forty-three of gases, which at 0° C. and 760 mm., occupy about 280 times the volume of the original powder. That the temperature of explosion is about 2,200° C., and the tension of the products, when the powder entirely fills the space in which it is fired, is about 6,400 atmospheres, or forty-two tons per square inch.

When fired in the bore of the gun it was shown that the work on the projectile is effected by the elastic force resident in the permanent gases, but the reduction of temperature, due to the expansion of the permanent gases, is in a great measure compensated for by the heat stored up in the liquid residue. The total theoretical work of gunpowder when expanded indefinitely (as for instance in a gun of infinite length) was deduced from the data which they accumulated as about 486 foot tons per pound of powder.

They further ascertained that the fine grain powders furnish decidedly smaller portions of gaseous products than large grain or cannon powders; that the variations in the composition of the products of explosion, in a closed vessel, furnished by one and the same powder, under different conditions as regards pressure, and by two powders of similar composition, under the same conditions of pressure, are so considerable that no chemical expression can be given for the metamorphosis of a gunpowder of a normal composition, and that the proportions of the several constituents of the solid residue are quite as much affected by slight accidental conditions of explosion of one and the same powder in different experiments as by decided differences in the composition or in the size of the grain.

The subsequent researches of Berthelot and Vieille, and of Sarrau and Vieille showed that gunpowder was not singular in that its combustion products varied with the variations in the conditions prevailing in the firing chamber, but that this same rule held for gun cotton, picrates and other explosives, also, and that consequently the chemical reaction taking place and the physical phenomena attending them were changed with these varying conditions, and more particularly with variations in the density of loading.

Before the invention of the instruments of precision above alluded to, guns were constructed largely on principles deduced from observations of exterior phenomena, and powder was manufactured largely by rule of thumb. With the ability to determine quantitatively their behavior, each has been studied in a scientific manner and improved by rational methods.

By their use the real importance of uniformity in chemical and physical composition was demonstrated for the powder, and the means by which to "prove powder" before issue were supplied, while rational blending, by which to minimize the irregularities incident to the best commercial processes was made possible. At the same time greater uniformity in granulation was secured; the best form of grain was developed for great guns through the pebble to the mammoth, disk, pellet, sphere, cylinder, hollow cylinder, hexagon and cube to the hexagonal prism, with one canal, which is now generally adopted, and which is a modified form of the grain invented by Rodman; the size of the grain best adapted for a given gun was ascertained, and the size rose trom one-sixth of an inch, as used in the 15-inch S. B., to fhe hexagonal prism one inch in height by 1.36 inches in diameter; the density of the grain rose from 1.60 to 1.86; the effect of prearranged variations of density in grains, as proposed by Doremus and carried out in the Fossano powder, was determined; and the important part which moisture played in the reactions going on in the chamber with the necessity for introducing it into the grain in definite quantities and retaining it there within very narrow limits was discovered. In fact these methods of inspection have become so precise and the powder specifications so severe that the manufacture of military gunpowder is now a most difficult art, and the maker must not only watch the barometer and thermometer and hygrometer to determine his action at each step of his process, but according to one authority, he must "vary his treatment with each passing cloud," and notwithstanding all precautions, it is no uncommon thing for the best makers to have their product rejected at the proving ground.

Besides these improvements in black gunpowder, which have resulted from our ability to accurately gauge its performance, these instruments have shown us that it is possible to avail ourselves of the energy stored up in underburned charcoal or carbohydrates if we but modify the brusqueness incident to mixtures containing them by adopting the proper size, form, hardness and density for the grain, and this has resulted in the cocoa or brown prismatic powders which have come into very extented use since 1880.

The valuable properties of the compressed powder were then applied for use in small calibers and enabled Hebler to realize a marked increase in efficiency for his rifles, and in these forms the limit of efficiency of gunpowder appeared to be reached.

But while this was being accomplished, progress was being rapidly made along other lines which we will briefly point out.

Among the other inventions in gunnery which preceded the invention of smokeless powder, and made its use possible or essential, we may mention the introduction of rifling, by which greater accuracy of fire and a higher velocity and penetrating effect is obtained, and which, while invented by Gaspard Zollner, of Vienna, in 1480, did not come into vogue until 1830, or general use until much later. Breech loading, which was known among the Chinese as early as 1313, but which has practically been developed since 1863, our civil war having been fought chiefly with muzzle loaders. Percussion caps, invented by Joseph Egg, in 1818, and adopted, with the nipple, in France in 1838. Self obturating metallic ammunition, which depended on the preceding invention, and which we owe apparently to Flobert, who introduced it for use, with a quick powder, in his parlor rifle in 1845, though it did not come into use for larger caliber for some years later, and then only after the discovery of a metal having the necessary ductility and strength from which to strike the shells and the perfecting of machinery for their economic and rapid production. Magazine rifles and machine guns, the earlier practical forms of the latter being the weapon exhibited by Dr. Gatling in 1867, and the French mitrailleuse, and which have now developed into the automatic machine guns, such as Maxim, Colt, Hotchkiss, and others possessing an almost incredible rapidity of discharge. Rapid fire large caliber guns, which, like the foregoing, depend for their development on the prior invention of the breech mechanism, and the metallic ammunition and which have reached calibers of six-inch diameter and throw 100-pound shot at the rate of six per minute, with a velocity of over 2,000 feet per second. Breech-loading, built-up steel rifles, which, while embodying the ideas of a gun of equal strength, as announced by Professor Treadwell, in 1843, the mechanical devices of Chambers patented in 1849, and the principles of initial tension, as expounded in Rodman's publication of the same year, have been developed, at least in this country, only since the appointment of the Gun Foundry Board by Secretary Chandler, and whose manufacture was then rendered possible only through the perfection which our machine tools had attained and the improvements achieved in the metallurgy of steel. Small caliber rifles, with steel or german-silver mantled bullets, which are sighted for about two miles, and whose projectile will pierce six men, standing one behind the other in close order, at 1,000 yards. And finally to the invention of range-finders or telemeters, through which by trigonometric or mechanical methods, the position of the far distant targets now in range of new weapons may be located with precision.

For it is evident that to use these precise and powerful weapons and instruments, with the accuracy and rapidity they are capable of, the atmosphere must remain clear, and the piece must remain clean, while at the same time the highest attainable velocity must be imparted to the projectile without an undue strain being brought upon the gun. Yet we have seen that Noble and Abel found that military gunpowder gives off, on combustion, fifty-seven per cent. by weight of ultimately solid matter which is either thrown into the atmosphere to produce smoke or left as a residue to foul the bore. How considerable this smoke producing capacity of gunpowder is may be estimated if we take a Gatling firing 1200 rounds of small arm ammunition per minute (and this by no means expresses the highest attainable speed to-day) and assume that all the solid matter is driven out the gun, when we shall find that each minute six and six-tenth pounds of finely divided solid matter will be projected into the atmosphere. Add to this, in a general engagement, the smoke from the great guns, which, as with the 110-ton gun, can project 528 pounds of this solid product at each discharge, and that coming from the rapid fire, and magazine rifles, and it is obvious that unless a favorable breeze is blowing or other favorable atmospheric conditions prevail, the force or ship will soon be enveloped in an opaque cloud of smoke and be at the mercy of an invisible foe. It is, I repeat, conditions such as these which have rendered smokeless powder, of good ballistic qualities, a great desideration, if not an absolute necessity.

While the development of the projectile, the musket, the machine gun, and ordnance; the perfection in the compositions, forms, and manufacture of gunpowder; and the invention of the instruments and devices for gauging and controlling their performance was going on, chemists were engaged in adding their contributions to the fund of human knowledge in the field of explosives. In 1788 Hausmann discovered "picric acid," in 1800 Howard discovered mercuric fulminate, in 1845 Schönbein discovered gun cotton, in 1845 Sobrero discovered nitroglycerin, in 1875 Nobel invented explosive gelatine, and in the meantime, or subsequently, numerous allied nitro-substitution compounds, nitric ethers and diazo-bodies, less generally known than those above enumerated, were produced, and identified, and shown to possess explosive properties.

The earlier experimental tests of these bodies proved that not only were some of them more powerful or more violent explosives than gunpowder, but that no smoke accompanied their explosion, since the products of their explosive decomposition were gases or vapors at the prevailing temperatures and efforts were put forth soon after their discovery to adapt them for use as propellents. These, together with various organic solids, and liquids to serve as solvents and hardening agents and ammonium and barium nitrates to serve as oxidizing agents were known and at hand.

The earliest experiment with smokeless powder was probably that made by Howard, in 1800, when he tested the properties of his newly discovered mercuric fulminate and found that though this violent agent produced little smoke, imparted a low velocity to the projectile and but a slight recoil to the piece, it burst the chamber, and demonstrated its unfitness to compete with gunpowder as a ballistic agent. Nevertheless this substance has since found a limited use, when mixed with solid diluents which act as restrainers, in ammunition for parlor rifles, and it is noticeable that when firing this ammunition there is little smoke and a scarcely audible report attending the discharge.

In 1806 Grindel carried out a somewhat extended series of experiments with a view to substituting ammonium nitrate for potassium nitrate as the oxidizing agent in gunpowder mixtures but the deliquescent character of the ammonium salt rendered the powder made with it useless under the then existing conditions, and has proven a formidable obstacle to its use in many of the attempts subsequently made. The fact, however, that the products of its combustion, at the prevailing temperature, are wholly gaseous rendered it a tempting material to inventors of smokeless powders and it has been more recently used, among others, by F. Gaens, who, in 1885, patented, in Germany, his so-called " Amide Powder," produced by mixing eighty parts of ammonium nitrate and 101 parts of potassium nitrate, with forty parts of charcoal. He claimed that this mixture was not hygroscopic and was practically smokeless, and he held that by the reaction consequent on the ignition, a potassamine was formed which was both volatile and explosive. Whatever the nature of the reaction, it appears from the reports that an ammonium nitrate powder was produced about this time in Germany and later in England, under the name of Chilworth Special, which possessed remarkable ballistic properties and yielded comparatively little smoke, which speedily dispersed, and which bore exposure very well until the humidity of the atmosphere approached saturation.

It is possible that the ammonium nitrate used may have been produced by Benker's process, in which the salt is formed by metathesis from solutions of sodium nitrate and ammonium sulphate exposed to a temperature of —15°, or below, for it is claimed that the ammonium nitrate which crystallizes out under these circumstances is of extraordinary purity and not at all hygroscopic.

It would appear that though these ammonium nitrate powders are slightly hygroscopic, they may retain their good qualities for long times in the hermetically sealed cases used in fixed ammunition up to the six-inch rapid fire gun, but that we know that the small amount of water necessarily present produces marked changes during long periods of storage with varying temperatures and that the ammoniacal salts attack the copper of the shells. Besides, too, we must remember that ammonium nitrate in common with other ammonium salts gives off ammonia, when heated or exposed to the air, and becomes acid so that we are debarred from using it in the presence of any bodies affected by the acid.

The next step toward the development of our modern smokeless powder was taken when, soon after the discovery of guncotton, in 1845, attempts were made to use this material as a propellent. These experiments were made in Germany, France, and England, and a very extended series were carried on by

Major Mordecai, at the Washington Arsenal, but the material, owing to its form and the imperfection in its manufacture, proved too brisant and too irregular in its action, and so unstable on keeping as to undergo decomposition in storage. The material having been proved to possess many valuable qualities was not wholly abandoned, but it continued to be the subject of study by many chemists until in 1862, it seeming that Baron von Lenck had so perfected the methods for its manufacture and purification as to ensure stability and uniformity of composition. Austria adopted it as a propellent and supplied thirty howitzer batteries with guncotton cartridges.

This is the first instance in which a really smokeless powder was employed on any but an experimental scale and this powder foreshadowed in its composition and many of its characteristics, the best modern powders of the smokeless class. The guncotton as then made retained the fibrous condition of the original cotton and in the Austrian cartridges it was spun into thread and woven into circular webs like lamp wicks, or braided, or wound on wooden or paper bobbins, and so arranged in the piece as to secure the desired air spacing as well as to insure ignition from the front. As thus used, it was claimed to be uninjured by dampness; to require a charge of but one-fourth to one-third of that of the powder previously employed; to be capable of being regulated so as to produce widely varying effects at will; to leave no residue to foul the piece; and to produce no smoke, while the gases evolved were less injurious to both the piece and men serving it than those of gunpowder. At the same time it produced less heating effect on the gun.

Unfortunately, about this time, the factory at Hirtenberg, where the guncotton was made, blew up for some undiscovered cause, and accidents having occurred with the guns, the use of guncotton was abandoned by the Austrians.

Its fate seemed now to be sealed, but such was not the case, for the scene of action then passed to England, where Abel not long after succeeded in effecting a more complete purification of the body by pulping it prior to the final washing processes, thus cutting the tubular fiber into short lengths and rendering it possible to remove the last traces of acid retained within the tubes by capillarity and which had been the occasion of its decomposition with time. Having thus obtained his pulped, purified guncotton he compressed it into such forms as was desired, and in 1867 and 1868 he obtained with it some very promising results when used with field guns. But although comparatively small charges often gave high velocities of projection without any indications of injury to the gun, the uniform fulfillment of the conditions essential to safety proved then to be beyond control, and the military authorities not being, at that time, alive to the advantages that might accrue from the employment of a smokeless explosive in artillery, experiments were discontinued not to be resumed for nearly twenty years, and use was found for compressed guncotton in military and naval mining and especially in filling torpedoes, where it has been found the most efficient and satisfactory explosive thus far applied to this purpose.

But sportsmen, to meet whose wants and wishes many noteworthy improvements have been made in the arts, did appreciate the value, to marksmen, of smokelessness combined with high velocities and absence of fouling, and the progress made during the succeeding twenty years in the adaptation of organic nitrates to use as propellents was under their patronage and in response to their demands, and naturally, the first object sought was to so restrain the violence of the explosive that rupturing explosions, such as had occurred, could not be induced under the conditions in which the powder was to be used.

One of the first to realize a considerable degree of success was Captain Schultze, of the German artillery, who made a powder from well purified and partly nitrated wood. For this purpose he sawed the wood into sheets about one-sixteenth of an inch in thickness, which were passed through a machine that punched out discs or grains of uniform size. The grains were then deprived of their resinous matter by being boiled in sodium carbonate, washed, steamed, and then bleached with chloride of lime, when finally, after drying, the cellulose was nitrated in an acid mixture, such as is used for making guncotton. The nitrated wood was then steeped in a solution of potassium and barium nitrates, and when dry the powder was finished. By this means a nitrocellulose was produced which was diluted with unconverted cellulose and metallic nitrates, which were so intimately mingled that a fairly even rate of combustion was obtained though abnormal results were not wholly avoided.

The advantage of using nitrates and combustible organic substances as diluents was soon recognized ; and, as a consequence, many powders of this nature were devised, some thirty of them having been produced and many of these put on the market, in which we find that potassium, sodium and barium nitrates, and potassium chlorate were used as oxidizing agents and sugar, cellulose, charcoal, sulphur, starch, dextrin, gums, resins, and paraffine as combustible diluents and cementing agents. All, however, approximated black gunpowder, as regards physical structure and none attained to complete success as regards uniformity of fire and reliability of pressure.

In 1882 Messrs. Reid and Johnson patented the process for making E. C. powder, in which the pulped nitrocellulose and nitrates was agglomerated into grains by revolving the moistened mass in barrels, drying the grains, moistening with ether to harden them, and then coloring them with aurine.

About 1885 Messrs. Johnson and Borland produced the J. B. powder, in which a new idea, as regards powder manufacture, was introduced, though it had been used elsewhere for many years. The inventors mixed nitro cotton with barium nitrate and with or without charcoal or torrefied starch and granulated the mixture in a revolving drum, while the water was admitted in a fine spray. When granulated the grains were dried and then moistened with a solution of camphor in petroleum spirit, and after a time heated in a water jacketed vessel to evaporate the benzine, and the bulk of the camphor. By this treatment the grains were hardened and rendered more slowly inflamable.

As this method of treatment resembles in some particulars that followed in the production of celluloid, though it differs in details, and as several of the smokeless powders are made by methods which are adapted from this art, you will pardon me if I briefly describe it.

Celluloid is made from that form of cellulose nitrate known as nitro-cotton or soluble guncotton, and which is produced by immersing unsized and uncalendered tissue paper for a short time in a comparatively weak acid, both being kept at a moderately high temperature. This nitro-cotton is pulped in a rag engine, dried and moistened with camphor spirits. If a considerable portion of camphor spirits be added, and the mixture be allowed to stand for awhile, the mass becomes converted into a soft translucent amber gum; with more of the spirit the nitro-cotton will be completely dissolved; but as carried out, the proportion of spirit added is insufficient to produce a very apparent change.

The mixture is now taken to incorporating rolls or "grinders," (as they are called in the caoutchouc industry), where it is intimately mixed and well pressed; when the particles cohere and the whole becomes converted into a plastic, translucent homogeneous mass which behaves like India rubber and resembles it superficially in every particular but color. After incorporation, by cutting the length of the roll, the mass may be stripped off in one continuous, coherent sheet, which on exposure to the atmosphere, through which the spirit and camphor are volatilized, hardens to a hornlike mass.

In the manufacture of a smokeless powder by this means, it is customary to mix with the nitro-cotton or mixed cellulose nitrates, a small proportion of other nitrates in order to effect complete combustion and a restrainer to assist in bringing the rate of combustion within normal limits; and this mixing is easily effected on the incorporating rolls. Barium nitrate is the salt which is perhaps most largely used, and it is preferred because it is very permanent, contains a fair proportion of available oxygen which it yields with comparative readiness, and possibly because the carbonate which is formed by the combustion has so high a specific gravity that it settles with considerable speed.

Other solvents besides camphor spirits are employed when the higher cellulose nitrates are used in the manufacture of the powder. Thus Engel takes a cellulose nitrate prepared from wood, while Glaser employs that prepared from paper or cardboard and treats it, when dry, with ethyl acetate or acetone, the action of the solvent being aided by mechanical kneading in a suitable vessel until a viscid paste or gelatinous mass is obtained with which the barium nitrate and a hydrocarbon, such as naphthalene, is incorporated. The mass is then formed into any desired shape and the solvent is allowed to evaporate or is distilled off by any suitable means when the powder is left as a dense horny material, with a glassy fracture, which can be readily granulated.

The first military smokeless powder of the modern class was made in France in 1886 by Vieille, and is said to have been compounded of cellulose nitrates mixed with picric acid, but it was soon abandoned in favor of the Poudre B., which consisted of cellulose nitrates alone, or Poudre B. N., which consisted of these nitrates mixed with barium nitrate and potassium nitrate as oxidants, and sodium carbonate as a neutralizer. Both these mixtures were condensed and hardened to a celluloid-like mass by means of a solvent like ether-alcohol, ethyl acetate or acetone.

Excellent ballistic results have been reported from France as being obtained with these powders, and they have been adopted by the French government. At the same time similar mixed cellulose nitrate powders have been produced and used in Germany, Austro-Hungary and Switzerland; the Weteren, Troisdorf and Von Förster powders being of this class. Notwithstanding that these have so long been known, our government has, with regal graciousness, recently granted a patent to two of its officers for a powder of this composition.

These are made by mixing the ingredients together with the solvent in a kneading machine of the Werner and Pfleiderer class, in batches of one to two hundred weight, until it is converted into a dough, when it is incorporated and the solvent partly driven off by putting on the grinding rolls, by which means it is also formed into continuous sheets, whose thickness is fixed by the set of the rolls. It is preferable where thick masses are desired to first roll into thin sheets so as to evaporate the solvent as completely as possible from the gelatinized mass, and then by piling the thin sheets on one another, weld them together by running them through the rolls. They are then granulated by passing them under a set of revolving circular knives which cut them first into strips and then into rectangles of the desired size and shape. These powders are dense, hard and hornlike in appearance.

Following Vieille by about two years,[1] Nobel invented ballistite, which practically is a modified explosive gelatine, differing from it only in that while the gelatine consists of ninety-three per cent. of nitroglycerin, and seven per cent. of nitro-cotton, ballastite contains about forty per cent. of nitro-cotton and one to two per cent. of anilin or diphenylamin, which is added to the nitroglycerol nitro-cotton mixture as a neutralizing agent to ensure stability. At first the solution of the gun-cotton and gelatinization of the mixture was effected by means of camphor and later by means of benzene, but it is now produced under the English patent of Lundholm and Sayer of 1889. They discovered that while dry nitro-cotton is but slightly soluble in nitroglycerin even at moderately high temperatures, when mixed with warm water and stirred up by compressed air, gelatinization sets in and solution may be completed by pressing out the water and working in the grinder. Flexible, transparent rubber-like sheets are formed, which may be cut into flakes in cutting machines of the usual type, or in pastry cutters, or may be squirted through spaghetti machines, as is done in Italy, where these cords or threads of ballistite are known as "Filite."

It is curious to note how many of the machines devised for bread making, pastry cutting and macaroni forming, have been employed in the manufacture of smokeless powder.

In 1889 Sir Frederick Abel and Professor James Dewar secured their patents on cordite, which like ballistite, contains nitroglycerin and cellulose nitrate, but whereas ballistite is made from nitro-cotton alone, cordite is made from "gun-cotton" containing from ten to twelve per cent. of nitro-cotton, to which is added a little tannin, dextrin or vaseline to serve as a restrainer. The gelatinization is effected by means of acetone,

1 English Patent, January 31, 1888.

the mixture being kneaded to a dough in a water-jacketed kneading machine, compacted in a mould in a preliminary press, and the mould transferred to a spaghetti machine, where the explosive is squirted into cords. As these cords issue, they are reeled on bobbins, which are placed in the drying house to drive off the acetone. When this is completed the product of ten pressings is wound from ten one-strand reels on to one ten-strand reel and then the cordite on six ten-strand reels is wound on one drum, making a cord of sixty strands, which in short lengths forms the thirty and one-half grains charge for the magazine rifle. For the higher calibers the cords are cut in lengths as they issue from the press, dried and made up into bundles. Cordite is an elastic rubber-like mass with a light to dark brown color.

Analogous to these in composition, in that they consist of nitroglycerin with cellulose nitrates, are many powders, such as amberite, Maxim's powder, Leonard's powder, P. P. G., Peyton's powder, German smokeless powder and others, and they differ in but slight particulars. Thus Curtis and André *blend different cellulose nitrates* before incorporation so as to secure a definite nitrogen content, and then cement by ether-alcohol ; Maxim restrains his powder with castor oil ; Leonard restrains his with lycopodium, and adds urea crystals as a neutralizer ; Walke claims to make P. P. G. from a nitro-cellulose, which is not gun-cotton, and so on.

The employment of nitro substitution compounds as bases for smokeless powders has been comparatively limited. Over twenty years ago Designolle invented powders made by mixing potassium picrate, potassium nitrate and charcoal in various proportions. Borlinetto produced them from picric acid, sodium nitrate and potassium dichromate. Abel and Brugère from ammonium picrate, potassium nitrate and charcoal, and more recently Nobel from ammonium picrate, barium nitrate and charcoal. Within a few years past a powder has been manufactured in this country and put upon the market as a sporting powder, which was composed of ammonium picrate, potassium picrate, and ammonium dichromate, but I understand it has given such irregular and abnormal pressures that its manufacture has been discontinued.

While these powders may have been smoke-weak as compared with gunpowder, it is difficult to understand how, in the presence of such amounts of metallic radicles, they could have been smokeless. A powder, however, which is made by Hermann Güttler, by dissolving nitro-lignin in molten dinitro-toluene and which he calls Plastomentite, may well possess this property, and it is reported to have given good ballistic results at the Bucharest tests of 1893.

The powder called Gelbite, and invented by Dr. Stephen H. Emmens, was also smokeless. This was made by an ingenious process in which paper in strips was nitrated to a moderate degree of nitration, then fumed with ammonia to neutralize the acid, and then treated with picric acid to neutralize the ammonia and form ammonium picrate. These strips were then rolled up into rolls as charges, but as might have been foreseen from a study of the behavior of gunpowder in guns and the study of the history of gun-cotton, this powder was too brusque in action and has been abandoned.

I began my own experiments with smokeless powder manufacture in 1889. At this time the remarkable results published from France, and the announcement that that country had adopted a smokeless powder, had produced their desired strategic effect. All her rivals were seeking to be equally well equipped and were hastening to adopt a powder even before its qualities were thoroughly proven. The newspapers contained remarkable accounts of their performances and alleged descriptions of their methods of production, which while interesting as news and conveying valuable suggestions, could not be relied upon as to accuracy in details.

At the outset, being familiar with the impossibility of securing absolute uniformity and constancy of composition in physical mixtures like gunpowder, and realizing how important this feature was with our precise modern weapons, and when employing an explosive possessing great energy, I determined to attempt to produce a powder which should consist of a single substance in a state of chemical purity. This was a thing which I had not known of having been done, nor have I yet learned that any one else has attempted it. Among the bodies at command, the nitric ethers seemed most available, and of these cellulose nitrate seemed for many reasons the most promising.

There are, as you are aware, several of these nitrates (authorities differ as to the number) which differ in their action towards solvents, though all except the most highly nitrated are soluble in methyl alcohol. In the commercial production of cellulose nitrate certainly, and so far as I have observed under all circumstances, when nitrating cellulose the product is a mixture of different cellulose nitrates. Even in the perfected Abel process for making military gun-cotton, as carried out at the Royal Gun Powder Factory, at Waltham Abbey, according to Guttmann[1], the product contains as a rule, from ten to twelve per cent. of nitro-cotton.

[1] Manufacture of Explosives, 2, 259, 1895.

Consequently I began by purifying my dried pulped military gun-cotton, which was done by extracting it with hot methyl alcohol in a continuous extractor, and when this was completed the insoluble cellulose nitrate was again exposed in the drying room. The highly nitrated cellulose was then mixed with a quantity of mono-nitro-benzene, which scarcely affected its appearance and did not alter its powdered form. The powder was then incorporated upon a grinder by which it was colloidized and converted into a dark translucent mass resembling India rubber. The sheet was now stripped off and cut up into flat grains or strips, or it was pressed through a spaghetti machine and formed into cords, either solid or perforated, of the desired dimensions, which were cut into grains. Then the granulated explosive was immersed in water, boiling under the atmospheric pressure, by which the nitro-benzene was carried off and the cellulose nitrate was indurated so that the mass became light yellow to gray, and as dense and hard as ivory, and it was by this physical change in state, which could be varied within limits by the press that I modified the material from a brisant rupturing explosive to a slow burning propellent.

This is the powder which I styled indurite, and which has been popularly known as the Naval Smokeless Powder.

I was satisfied that I was justified in starting on this new practice in powder-making when I found, on examination of the samples of foreign military powders[1] which later began to reach me officially, that they were heterogeneous mixtures as the old gunpowder is and that they contained matter which was volatile at ordinary temperatures, and when I learned that the nitroglycerin powders cracked from freezing.

I was still more satisfied when I learned the results of the proving tests which were all made except the chemical stability and breaking down tests by naval officers detailed for this purpose at the Proving Ground and elsewhere, and who had no prejudice in its favor. All of the numerous publications which have appeared about it have issued from headquarters, and I present the matter myself here for the first time.

I have appended the data from these trials to this address where. on inspection it will be seen, that after development, the powder in use, in successive rounds, gave remarkably regular pressures and uniform velocities. I was informed by the Chief of the Bureau before the firing trials, recorded in the tables began, that if I could produce a powder giving 2,000 feet initial velocity and but fifteen tons pressure, it would be a complete success. Inspection of the tables show that this was more than realized and that in two successive rounds in the

[1] Table I.

six-inch rapid fire gun, using twenty-six pounds of my powder and a 100 pound projectile, the pressures were 13.96 and 13.93 tons, and the velocities 2,469 and 2,456 feet per second respectively, while according to the Report of the Secretary of the Navy, 1892, page 26, "the powder manufactured for use in the six-inch rapid fire guns was stored at Indian Head proving ground, through a period of six months, covering a hot summer, and at the end of the time showed no change in a firing test."

On page 25 Secretary Tracy says, "It became apparent to the department early in this administration that unless it was content to fall behind the standard of military and naval progress abroad in respect to powder, it must take some steps to develop and to provide for the manufacture in this country of the new smokeless powder, from which extraordinary results had been obtained in Europe. With this object negotiations were at first attempted looking to the acquisition of the secret of its composition and manufacture. Finding itself unable to accomplish this, the Department turned its attention to the development of a similar product from independent investigation. The history of these investigations and of the successful work performed in this direction at the torpedo station has been recited in previous reports. It is a gratifying fact to be able to show that what we could not obtain through the assistance of others, we succeeded in accomplishing ourselves, and that the results are considerably in advance of those hitherto attained in foreign countries."

From this survey we see that all of the smokeless powders that have met with acceptance and proved of value as ballistic agents with the exception of Indurite are mixtures of one or more of the cellulose nitrates, or mixtures of these bodies, with nitroglycerin or some other oxidizing agent, like barium nitrate, and a restrainer or with a nitro substitution compound and that all have been condensed or hardened into a rubber-like or celluloid-like form, by which, even under the high pressures which obtain in the gun, they are expected to undergo combustion only and that at a moderate and regular rate.

In thus condensing the material, and in determining the best form of grain, it will be observed that we have been guided by the experience gained in the compression of gunpowder, and we have been able to effect this as we have by the experience gained in the development of celluloid, and we have been able to manipulate our product and shape it into grains only by adopting the methods and machines developed in the manufacture of food, while we have been able to test our product and check our results and thus ensure a more rapid and certain advance by the constant use of the pressure gauge and velocimeter. In my opinion, if these resources had not been at command and available the smokeless powder industry would not yet exist.

From what has been said it may properly be inferred that we seek in these new powders all the virtues of the old gunpowder with the addition that the new powder shall be smokeless, impart higher velocities while producing no greater pressures and that less of it shall be required to do the work. These requirements may be summed up as follows:

The conditions that a smokeless powder suitable for a propellent should fulfill are:

1. That it shall be physically and chemically uniform in composition.

2. That it shall be stable and permanent under the varying conditions of temperature and humidity incident to service storage and use for all time.

3. That it shall be sufficiently rigid to resist deformation in transportation and handling.

4. That it shall produce a higher or as high a velocity with as low a pressure as the service charge of black powder for a given piece.

5. That it shall be incapable of undergoing a detonating explosion.

6. That the products of its combustion shall be nearly if not quite gaseous so that there shall be no residue from it and little or no smoke.

7. That it shall produce no noxious or irrespirable gases or vapors.

8. That it shall not unduly erode the piece by developing an excessive temperature.

9. That it shall be as safe as gunpowder in handling and loading.

10. That it shall be no more than ordinarily dangerous to manufacture.

Most of these requirements have been satisfied in several of the powders, but time alone can determine the question of absolute stability and especially as the comparison is instituted with gunpowder which has been under observation for over 500 years.

We can and do apply tests whose results give us some confidence as I did when I exposed Indurite wrapped in felt in an iron vessel to a temperature of 208° F. for six hours without its undergoing change, and again at a temperature of 212° F. for twenty hours before any change was observed, and again to 5° F. without its being affected.

In fact from the outset I have advised the application of most rigid tests and drew up the following scheme for the Navy Department in July, 1891, by which to test Indurite.

"The most important requisite of powder, after passing the proof test, is that it shall retain its characteristics under all the conditions of storage or transportation which may obtain in the service or that, if any change does take place, it shall not cause the powder to develop under the "proof" conditions any greater pressure than it did at the time of proving, and that such falling off in velocity as may result from this change in the powder shall not be relatively greater than that which obtains for service black powder, and shall be uniform for the same conditions of exposure.

"In providing for this test I would first prove a ten pound lot to determine the maximum weight that will come within the limits fixed for pressure and velocity, and then I would load 1000 Winchester 30.1 cal. and 1000 Mannlicher shell with a charge some grains (say five) less than the maximum, so as to be doubly safe in case the pressure should become increased through the treatment to which the powder is subjected.

"The loading should be done with extreme care by skilled workmen in an especially clean and uniformly heated and dried room. The charges should be weighed on chemical balances and with all the precautions surrounding an analytical operation. The balls should be weighed and gauged, and the shell should be gauged so as to secure as nearly absolute uniformity as possible, while the caps and priming (if used) and wads should be identical for each shell of each 1000 lot.

"These being prepared, I would pack these ball cartridges precisely as if ready for issue to the service, and then I would store 385 Winchester's and 385 Mannlicher's in the regular magazine at the Naval Torpedo Station, and the same number of the same kind in the regular magazine at the Naval Ordnance Proving Ground. I would then draw from the magazine at the Torpedo Station twenty-five Winchester's and 25 Mannlicher's and fire them, using the muskets and measuring instruments which are to be used throughout the trials, and I would repeat this trial every month for three years, firing ten rounds of each form of ammunition and using the same muskets and instruments throughout. At the same time I would have an identical set of tests made at the Proving Ground, the same precautions being taken there regarding the instruments and tools. Throughout the tests a close watch should be kept on the magazines by means of maximum and minimum thermometers so that if abnormal results are obtained in firing it may be known whether or not any abnormal conditions have obtained in the magazine. This series of tests will consume 1540 rounds. It would, in my judgment, be of much value to store with these cartridges and fire with them an equal number of charges of standard service black powder, to be used as a standard for reference by which any error in the observations, or defects in the instruments may be detected.

"I would take eighty rounds of the Winchester's and eighty of the Mannlicher's and place them in an oven heated to 140° F. or thereabouts. At the end of one month twenty of each are to be drawn out and this to be repeated each month for four months. One half of each form should be proved at the Torpedo Station and the other half at the Proving Ground.

"I would take eighty rounds of the Winchester's and eighty of the Mannlicher's and subject them for two weeks to the freezing temperature, then for two weeks to a temperature of about 140° F., and then draw twenty of each, and this should be continued until the last forty drawn out have been exposed for eight weeks to freezing and eight weeks to the high temperature. The firing trials with these should be made as with preceding ones.

"The remaining shell should be stored in the regular magazine to be used in any test case which may arise or in any manner suggested by the results obtained in the tests described above.

"In the meantime tests could be made with the hand cut S. P. for the capacity of the powder to resist crumbling and dusting during transportation and the tendency of the fixed ammunition to explode *en masse* by the impact of projectiles, or by the explosion of a single cartridge in the midst of a box filled with them. The first can be effected by taking a pound or a kilogram of carefully sifted powder, placing in a copper vessel which it only partly fills, and attaching it to a shaft so that it will be continually and violently shaken, and allowing this to go on every working day for a week. The powder can then be sifted, using the same mesh as before, the weight of the dust found and the percentage of dusting for the given circumstances determined.

"In the trials for tendency to explode *en masse* fifty or forty-five caliber ammunition can be used and the weights of charges need not be very precise, but the ammunition should be packed in, as nearly as possible, the same way as would obtain in service practice."

We have seen that the development of smokeless powder has been rendered necessary by the improvement in the gun. It now appears that in consequence of the possession of the powder we must further improve the gun for we cannot in our present guns utilize all the energy now available. Experiments looking to this have been going on in France, where in a Canet ten cm. gun of eighty calibers, with a charge of 12.35 pounds of powder and a projectile weighing 28.66 pounds there was obtained the extraordinary muzzle velocity of 3366 feet per second, while the maximum pressure was 18.91 tons per square inch. Longridge, an English authority, deprecates the lengthening of the gun as it becomes too unwieldy and he advocates utilizing the energy of the gun by strengthening it so it will endure greater pressures and then using larger charges. He points out that if this Canet gun were reduced to forty-five calibers, and strengthened, we could obtain from it the same enormous muzzle velocity by increasing the charge to thirteen and a half pounds, though the pressure would rise to twenty-five tons per square inch.

What the result will be where authorities of standing disagree is impossible to foresee, but the fact is demonstrated that the powder is now more highly developed than the gun, and that while seeking for smokelessness, we have secured a propellent which is capable of producing much higher velocities than gunpowder, with all the additional advantages of flat trajectory, increased danger area, greater accuracy, and greater range which follow as consequences.

TABLE I.

COMPOSITION OF VARIOUS POWDERS.

Mark.	Nitro-Cotton.	Guncotton.	Barium Nitrate.	Potassium Nitrate.	Sodium Carbonate.	Volatile.	Cellulose.	Sodium Picrate.	Charcoal.	Humus.	Nitro-Glycerin.	Graphite.
B. N., Aug. 22, '90	26.84	44.42	18.25	3.08	4.92	2.05	....	....	....	....	....	....
B. N., Dec. 5, '90	29.79	40.54	19.00	5.81	3.87	1.50	....	....	....	....	....	....
B. N., June 3, '91	38.05	35.55	18.94	1.81	4.51	1.06	....	....	....	....	....	....
B. N., Aug. 12, '91	41.31	29.13	19.00	7.97	2.03	1.43	....	...	....	....	....	....
B. N., Oct. 16, '91	31.38	49.89	17.92	3.43	2.82	0.82	....	....	....	....	....	....
B. N_A., July 9, '90	31.27	40.52	18.42	6.62	2.58	1.25	....	....	....	....	....	....
B. N_C., Aug. 22, '90	32.62	39.44	18.90	7.45	1.39	1.63	....	....	....	....	....	....
B. N_C., Dec. 5, '90	32.03	39.52	19.36	5.17	3.75	0.92	....	....	....	....	....	....
B. N_L., Oct. 16, '91	72.09	26.49	....	....	....	0.92	0.47	trace	....	....	....	....
French Powder, June 3, '91	73.11	25.98	....	....	....	0.89	....	trace	....	....	....	....
Poudre B., Oct. 16, '91	32.86	66.00	....	....	....	1.14	trace	....	....	....	....	....
Walsrode, S. P., Sept. 4, '90	12.08	86.28	....	....	0.93	0.72	....	....	....	....	....	....
[1]Wetterin, S. P., March 18, '91	46.70	30.35	....	....	....	9.66	....	....	12.39	0.90	....	....
[2]Wetterin, S. P., March 18, '91	48.15	30.73	....	....	....	8.22	....	....	12.12	0.77	....	....
[3]Wetterin, S. P., March 18, '91	47.78	25.87	....	....	....	14.69	...	....	10.84	0.80	....	....
Lebel, Sept. 27, '90	28.21	69.45	....	....	0.80	1.49	....	....	....	....	....	....
German, Oct. 15, '90	10.00	88.43	....	....	0.56	0.99	trace	....	....	....	....	....
Cordite, Sept. 17, '90	7.04	29.20	....	....	[4]6.17	1.30	0.23	....	....	....	56.04	....
Cordite, Oct. 11, '90	8.45	27.72	....	....	[4]4.23	1.45		....	....	....	58.13	....
Ballistite, Sept. 19, '90	44.58	....	....	....	2.44	....	....	....	....	....	52.99	....
Nobel's, S. P., Oct. 15, '90	53.26	0.97	....	....	3.42	0.41	....	....	....	....	41.95	....
Schwab, Nov. 7, '90	77.41	20.42	....	....	0.69	1.47	....	....	...	...	....	trace

[1] Small arm. [2] Small cube. [3] Large cube. [4] Includes dextrine.

Mark.	Nitro-Cotton.	Guncotton.	Barium Nitrate.	Potassium Nitrate.	Sodium Carbonate.	Volatile.	Cellulose.	Sodium Picrate.	Charcoal.	Humus.	Nitro-Glycerin.	Graphite.
[1] Reg. Y., 283, Nov. 14, 90	56.46	....	....	....	0.37	0.33	....	....	....	....	42.84	trace
[2] Reg. Y., 283, Nov. 14, '90	52.10	....	....	...	0.36	0.39	....	....	....	....	47.17	....
German, S. P., Aug. 7, '91	48.83	7.45	....	....	....	0.53	....	....	....	....	43.15	trace
Maxim, flat, June 3, '92	8.14	71.19	....	....	2.58	0.19	....	....	....	....	[3]17.90	....
Maxim, cord, June 3, '92	6.84	46.60	....	....	1.70	0.26	....	....	....	....	[3]44.60	....
									Manchester yellow			
Rifleite, May 7, '92	22.48	74.16	....	....	....	0.84	....	....	2.52	....	....	trace
									Aurine			
S. K., May 6, '92	20.39	57.73	18.08	1.24	....	1.43	....	....	1.11	....	....	....
S. R., May 7, '92	28.18	46.97	19.97	2.35	....	1.45	....	....	1.c6	....	....	....
	[4]lignin	[5]lignin			$NaNO_3$		[6]lignin		Aurine			
E. C., Nov. 9, '91	53.57	1.86	34.26	1.48	3.07	1.17	3.12	....	0.55	....	....	....
									Paraffin			
Schultze, Sept. 24, '91	27.71	32.66	27.62	2.47	2.88	1.48	1.63	....	4.20	....	....	....
Brackett, Sept. 26, '91	31.43	13.70	....	....	19.76	2.93	13.22	....	....	18.94	....	....
American Wood Pd., Jan. 27, '91	24.90	30.07	....	....	9.76	5.83	19.55	....	....	9.89	....	....
" Grade C., Aug. 27, '91	29.25	14.06	....	....	15.27	3.01	28.08	....	....	10.32	....	....
" " E., Aug. 27, '91	24.91	25.62	....	....	17.81	3.86	19.15	....	....	8.65	....	....
" 10-Bore Trap, Aug. 29, '91	33.21	18.69	....	....	14.82	2.36	20.27	....	....	10.65	....	....
" 12-Bore Trap, Aug. 31, '91	29.47	21.85	....	....	13.38	3.14	16.59	....	....	15.62	....	....
					sodium picrate				Charcoal			
Reine Powder, Dec. 8, '90	....	....	48.44	....	46.31	1.18	....	....	4.07	....	....	....

[1] Five mm. [2] One mm. [3] Includes castor oil. [4] Soluble nitro-lignin. [5] Insoluble nitro-lignin. [6] Unconverted lignin.

Table II.

Tests of Indurite at Naval Ordnance Proving Ground.

Powder.	*Gun.*	*Weight of Charge.*		*Projectile.* *System.*	*Projectile.* *Weight.*	*Pressure.* *Tons.*	*Velocity.* *Foot—seconds.*
Service Black.	Hotchkiss 1 Pdr.	140 grams		Housing	465 grams	11.2	1694
"	"	150 "	Small ignition disk in each charge.	"	450 "	11.2	1690
"	"	150 "		Common shell	450 "	....	1793
"	"	150 "		"	450 "	....	1841
S. P. No. 151, No. 3 T.	"	50 "		"	450 "	....	1341
"	"	70 "		"	450 "	....	1811
"	"	80 "		"	450 "	....	2150
"	"	80 "		Housing	460 "	13.0	1877
"	"	80 "		"	460 "	15.0	1896
"	"	75 "		Common shell	450 "	....	1816
"	"	75 "		"	450 "	....	1760
"	"	75 "		"	450 "	....	1894
S. P. No. 153, No. 4 T.	"	70 "		Housing	465 "	14.2	1774
"	"	70 "		"	465 "	14.4	1616
"	"	70 "		Common shell	450 "	About 12.13 tons	1774
"	"	70 "		"	450 "	"	1776
S. P. No. 157, No. 4 3/16 T.	"	70 "		Housing	465 "	8.2	1082
"	"	90 "		"	465 "	11.2	1363
M. N. 2.	"	100 "	Ignition charge 8 grams. N. X. 9 (Blk. fine grain). Ignited at rear.	"	....	13.5	Lost—missed wires
"	"	90 "		Common shell	Not obs.	Not obs.	1584
"	"	90 "		"	....	9.0	1281
S. P. No. 140.	Hotchkiss 3 Pdr.	100 "		"	3 pounds	1.5	882
"	"	200 "		"	3 "	4.3	Lost
"	"	300 "		"	3 "	15.0	2186
"	"	300 "		"	3 "	12.2	Lost
"	"	300 "		"	3 "	12.0	Lost
"	"	300 "		"	3 "	12.3	2105
"	"	310 "		"	3 "	14.9	2216
"	"	310 "		"	3 "	14.8	2250
S. P. No. 148.	"	275 "		"	....	....	....
"	"	300 "		"	....	9.0	1766

TESTS OF INDURITE AT NAVAL ORDNANCE PROVING GROUND.

Powder.	*Gun.*	*Weight of Charge.*			*Projectile.* *System.*	*Weight.*	*Pressure.* *Tons.*	*Velocity.* *Foot—seconds.*
S. P. No. 148.	Hotchkiss 3 Pdr.	315	"	Small ignition disc. Priming 89. N. X. Q.	Common shell	....	10.4	1921
"	"	325	"		"	....	11.2	2017
"	"	335	"		"	....	12.2	2076
"	"	338	"		"	....	11.0	1995
"	"	345	"		"	....	15.4	2187
"	"	340	"		"	....	14.3	2166
"	"	340	"		"	....	11.5	2126
"	"	343	"		"	....	18.0	2214
S. P. No. 153, No. 4 T.	"	250	"		"	3.3 lbs.	11.3	1887
"	"	275	"		"	3.3 "	13.6	2051
"	"	300	"		"	3.3 "	24.0	2281
"	"	275	"		"	3.3 "	16.8	1975
"	"	270	"	R	"	3.3 "	14.5	2000
"	"	270	"	"	"	3.3 "	16.0	2018
"	"	270	"	"	"	3.3 "	22.5	2050
S. P. No. 141 a.	Hotchkiss 6 Pdr.	200	"	Ignition charge 8 grams N. X. L. Blk. fine grain.	"	6 "	7.2	1085
"	"	250	"		"	6 "	9.0	1237
"	"	300	"		"	6 "	9.2	1453
"	"	300	"		"	6 "	9.2	1453
"	"	325	"		"	6 "	9.6	1584
"	"	350	"		"	6 "	9.6	1648
"	"	375	"		"	6 "	13.6	1813
"	"	375	"		"	6 "	10.6	1738
"	"	400	"		"	6 "	16.0	1903
"	"	390	"		"	6 "	14.3	1841
"	"	392	"		"	6 "	14.3	1855
S. P. No. 153, No. 4 T.	"	200	"		"	6 "	6.5	1330
"	"	250	"		"	6 "	8.6	1544
"	"	300	"		"	6 "	9.9	1679
"	"	350	"		"	6 "	16.7	1728
"	"	340	"		"	6 "	15.0	Lost

Tests of Indurite at Naval Ordnance Proving Ground.

Powder.	Gun.	Weight of Charge.		Projectile. System.	Projectile. Weight.	Pressure. Tons.	Velocity. Foot—seconds.
S. P. No. 153, No. 4 T.	Hotchkiss 6 Pdr.	340 "		Common shell	6 lbs.	18.0	Lost
S. P. No. 157, No. 4 3/16 T.	"	300 "	Priming 8 grams N. X. L.	"	6 "	5.0	1324
"	"	350 "		"	6 "	6.5	1473
"	"	400 "		"	6 "	11.4	1775
"	"	420 "		"	6 "	9.1	1738
S. P. No. 148, No. 4.	"	300 "		"	6 "	7.6	1543
"	"	350 "		"	6 "	11.1	1751
"	"	365 "		"	6 "	12.0	1818
"	"	372 "		"	6 "	12.5	1835
"	"	382 "		"	6 "	11.0	1862
"	"	392 "		"	6 "	13.0	1920
"	"	410 "		"	6 "	13.6	2002
"	"	418 "		"	6 "	15.0	2047
"	"	418 "		"	6 "	15.0	2047
S. P. No. 148, No. 4.	"	418 "		"	6 "	14.8	2043
"	"	418 "		"	6 "	14.0	2012
"	"	418 "		"	6 "	13.0	1992
M. N. 2.	"	400 "	Priming charge 25 grams of fine grained powder in each charge.	"	6 "	9.5	1724
"	"	480 "		"	6 "	11.6	1988
"	"	480 "		"	6 "	12.0	1992
"	"	440 "		"	6 "	8.0	1702
"	"	450 "		"	6 "	8.0	1728
"	"	450 "		"	6 "	8.1	1735
S. P. No. 146 b.	4-in. No. 11.	4.5 pounds		"	33 "	13.5	1762
S. P. No. 146 a T.	"	4.5 "		"	33 "	10.9	1820
S. P. No. 149 T.	"	2.25 "		"	33 "	3.5	1177
"	"	4.50 "		"	33 "	10.3	1845
"	"	4.75 "		"	33 "	11.5	1945
"	"	5.00 "		"	33 "	13.6	2046
"	"	5.15 "		"	33 "	14.0	2080
"	"	5.25 "		"	33 "	14.2	2083

Tests of Indurite at Naval Ordnance Proving Ground.

Powder.	*Gun.*	*Weight of Charge.*		*Projectile. System.*	*Projectile. Weight.*	*Pressure. Tons.*	*Velocity. Foot—seconds.*
S. P. No. 149.	4-in. No. 11.	5.00 "		Common shell	33 lbs.	13.6	Lost
"	"	5.35 "		"	33 "	15.2	Lost
"	"	5.30 "		"	33 "	15.0	1943
"	"	5.30 "	Ignited at rear.	"	33 "	15.0	2122
S. P. No. 159 M.	"	3.5 "		"	33 "	9.5	Lost
"	"	4.05 "		"	33 "	10.3	1912
"	"	4.2 "		"	33 "	11.0	1936
"	"	4.8 "		"	33 "	12.0	1990
"	"	5.2 "		"	33 "	14.7	2125
"	"	5.2 "		"	33 "	14.8	2134
"	"	5.3 "		"	33 "	14.8	2145
S. P. No. 149 M.	"	5.3 "		"	33 "	15.0	2160
"	"	5.3 "		"	33 "	14.8	2158
S. P. M. N. 2 (163).	"	4 "		"	33 "	7.5	1591
"	"	5 "		"	33 "	10.2	1888
"	"	5.5 "	One ignition grain in base of each charge. Ignition at rear.	"	33 "	12.35	1993
"	"	5.5 "		"	33 "	12.35	1997
"	"	4 "		"	33 "	7.3	1606
"	"	4 "		"	33 "	7.2	1569
"	"	5 "		"	33 "	10.5	1892
"	"	5 "		"	33 "	10.2	1865
S. P. No. 159 M. N. 2.	6-in. No. 120.	9.5 "		"	77 "	6.5	1728
"	"	13⅛ "		"	77 "	10.0	2131
"	"	15 "		"	77 "	11.9	2281
"	"	16½ "		"	77 "	13.6	2415
S. P. M. N. 3, No. 162.	"	11½ "		"	100 "	5.0	1466
"	"	15 "		"	100 "	7.9	1784
"	"	18 "		"	100 "	11.0	2060
"	"	20 "		"	100 "	13.2	2212
"	"	21 "		"	100 "	14.4	2312
" After 6 mos.	"	14 "		"	100 "	6.7	1678
" storage.	"	20 "		"	100 "	12.0	2170

Tests of Indurite at Naval Ordnance Proving Ground.

Powder.	Gun.	Weight of Charge.		Projectile. System.	Projectile. Weight.		Pressure, Tons.	Velocity. Foot—seconds.
S. P. M. N. 6.	6-in. No. 120.	15	"	Common shell	100	lbs.	5.06	1535
"	"	19	"	"	100	"	7.30	1793
"	"	23	"	"	100	"	11.20	2151
"	"	25	"	"	100	"	12.56	2369
"	"	26	"	"	100	"	13.96	2469
"	"	26	"	"	100	"	13.93	2456
S. P. M. N. 3. No. 162.	"	7	"	"	50	"	4	1496
"	"	11	"	"	50	"	10	2108
"	5-in. "	7	"	"	50	"	4	1496
"		11	"	"	50	"	10	2108
"		12	"	"	50	"	12	2256
"		12.75	"	"	50	"	13.2	2383
"		13.12	"	"	50	"	14.2	2474
"		13.4	"	"	50	"	15.6	2578
S. P. M. N. 2 (168).	4-in. R. F. No. 8.	5½	"	"	33	"	12.4	1997
"	"	5½	"	"	33	"	13.4	2042