CHAPTER XXIX

IGNITION AND DETONATION

Definition of explosion : Development of explosion : Initiators : Fulminates and azides : Manufacture of caps, etc. : Precautions : Wet process : Dry process : Drying : Drum method : Jelly-bag method : Charging : Pressing : Varnishing : Inspection : Official definition : Testing caps : Percussion primers : Friction tubes : Electric tubes : Igniters : Detonators or blasting caps : Packing : Precautions : Disposal of waste : Testing detonators

Definition of explosion.

An explosive is a solid or liquid substance or mixture of substances which is liable, on the application of heat or a blow to a small portion of the mass, to be converted in a very short interval of time into other more stable substances largely or entirely gaseous.

The temperature of the products is always very high in consequence of the liberation of a considerable amount of heat in the chemical changes that take place.

The above definition excludes many objects which are capable of exploding, but are not explosives in the ordinary meaning of the word, and consequently do not form the subject matter of this book. Gaseous explosive mixtures, for instance, are of enormous technical importance, but are not the products of the explosives industry.

Development of explosion.

In the last chapter it was shown how explosions vary in power and violence. In this one the development of the explosive wave will be discussed and the methods of initiating it. When an explosive, such as a smokeless powder, is "ignited," it burns from the surface inwards in parallel layers with a velocity which depends upon the pressure, but even under several thousand atmospheres never exceeds a few metres per second : the ignition is communicated from layer to layer by the heat generated. On the other hand, when an explosive is detonated the wave of detonation proceeds apparently through the mass of unaltered explosive with a velocity of several thousand metres per second, changing the material as it proceeds : in this case the explosion is communicated by pressure, but possibly this pressure acts by suddenly raising the temperature by compression.

A mechanical mixture of different substances, no one of which is able to explode by itself, such as black powder, cannot be made to detonate properly, because the chemical change can only take place at the points where the

oxidizer and the combustible substances are in contact. Even under the most severe conditions as to pressure and initial shock the velocity of explosion does not exceed about 300 metres per second. But if saltpetre be replaced by potassium chlorate, which can be detonated, even when not mixed with combustibles, the case is quite altered and a high explosive is obtained, the velocity of detonation of which is several thousand metres per second.

When gunpowder is ignited it burns very rapidly, even if unconfined. The porosity of even highly compressed powder facilitates the spread of the flame. The rate of burning is affected comparatively little by pressure : hence the use of fine grain powder to ignite cannon cartridges.

Nitric esters, such as nitro-glycerine and gun-cotton, do not attain a very high rate of combustion when unconfined, even if in a state of fine division. This is apparently due to the fact that under these conditions the decomposition takes a different course from that which is followed when they are exploded in a confined space : the nitrogen is mostly set free in the form of nitric oxide or peroxide, and the heat liberated is very much less.

Initiators.

In the early days gunpowder was always ignited by means of a flame ; later sparks from a flint and steel were utilized to light a priming of mealed powder, which communicated the flame to the charge. Not until the nineteenth century was use made of small quantities of sensitive explosives that could be ignited by a blow. It was the discovery of fulminate of mercury, which rendered this possible, and this substance is still an essential constituent of most cap compositions. When used by itself in sufficient quantity to ignite gunpowder with certainty, the fulminate produces such a sudden pressure that it deforms the cap. Therefore it is mixed with other substances which diminish violence and at the same time increase the heat of explosion. Saltpetre, sulphur and mealed powder were formerly added, but now potassium chlorate and sulphide of antimony are usually employed ; some cap compositions contain all these constituents. Ground glass has also been used to increase sensitiveness, but it is not necessary when fulminate is present, and being chemically inactive it, of course, diminishes the power of the cap. For use with smokeless powders, cap composition should not contain more than about 20 per cent. of fulminate of mercury, otherwise the pressure generated will be too high. Numerous attempts have been made to devise cap compositions containing no fulminate, such as a mixture of chlorate of potash and sulpho-cyanide of lead, but although a considerable degree of success has apparently been achieved, such compositions have not come into general use, probably on account of the difficulty in attaining the uniformity necessary with mixtures containing no one constituent which is both sensitive and explosive, especially as mixing by grinding is from the nature of the mixture impossible.

In the case of ordnance the conditions are somewhat different from those

in small-arms : a larger quantity of material can be used, and a greater amount of force is available. Compositions can therefore be used containing no fulminate. They usually consist of potassium chlorate and antimony sulphide, together with a little sulphur to facilitate ignition and some glass powder to increase sensitiveness. The flash from this is communicated to some black powder, which in turn ignites the cartridge.

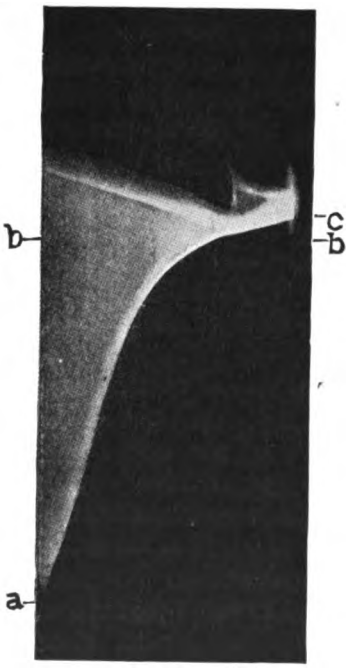

FIG. 101. Explosion of Mixture of Cyanogen and Oxygen (Dixon)

For the ignition of powders in fire-arms, heat only is required ; for the detonation of high explosives, on the other hand, a very sudden and intense blow is necessary, and this can only be obtained by means of an explosive which itself detonates with a velocity of several thousand metres per second. Detonators are always fired by means of heat supplied either by a burning fuse, or by a priming ignited by an electric current. When a light is applied to fulminate, at first it only burns with a velocity of about 10 metres per second, but the reaction becomes more and more rapid, and within an interval of time, which is probably not more than $\frac{1}{3000}$th of a second, detonation sets in. The transformation of combustion into detonation has been shown experimentally in the case of explosive gas mixtures, and may be clearly seen in the photograph by Dixon reproduced in Fig. 101. This is a reproduction of a photograph taken on a film travelling rapidly in the direction, *b* to *a*. The object photographed was a glass tube, *ac*, containing a mixture of cyanogen and oxygen. The mixture was ignited at the end, *a*, by means of an electric spark ; ignition proceeded with a moderate and fairly uniform velocity for a short time, then the velocity increased, and at the point, *b*, detonation suddenly set in, and then the detonation wave travelled on to the end, *c*, of the tube with a uniform velocity of several thousand metres per second. The detonation set in so violently that there travelled back from the point, *b*, a wave of compression, which was sufficiently powerful to raise the gas again to incandescence. This wave, which is called the " wave of retonation," moves with a velocity slightly less than that of the wave of detonation. From the end, *c*, of the tube the wave of detonation also is reflected back with somewhat lower velocity.

When a sensitive solid explosive, such as fulminate of mercury, is ignited, it probably behaves in much the same way as a gaseous mixture, but the

transition from burning to detonation is so rapid, and takes place in such a minute space, that it cannot be followed.

An explosive can be used successfully to initiate detonation only if, after ignition, it detonates within a very short interval, and before any considerable quantity has burnt away. That is to say, the distance, *ab*, which in the case of the gas mixture shown in Fig. 101 amounts to several decimetres, must not be more than a few millimetres, or preferably only a fraction of a millimetre. Recent developments in the manufacture of detonators are due to no one more than to Professor L. Wöhler, who has investigated a number of different explosives with regard to this property. He calls it initial velocity,[1] but it is really acceleration and not velocity. In 1907 he published, together with O. Matter, the results of experiments with a number of sensitive explosives[2] The following were some of the figures obtained :

	Density	Relative power in lead block c.c.	Temperature of ignition
Silver azide	3·38	22·6	290°
Mercury fulminate . . .	3·37	25·6	190°
Chlorato-trimercuraldehyde . .	3·00	15·3	130°
Diazobenzene nitrate . . .	1·46	43·1	90°
Nitrogen sulphide	2·11	39·2	190°
Sodium fulminate	1·65	14·9	150°
Basic mercury nitro-methane . .	2·45	7·5	160°

The power was determined in each case with 2 g. compressed into a detonator tube and fired with safety fuse in a lead block considerably smaller than that used for blasting explosives. Similar tubes were also fired standing on small lead plates : the results were in the order of the above list, silver azide perforating the plate most. Of all these explosives silver azide, mercury fulminate and the aldehyde are the only ones that have a sufficiently high acceleration to be of any use as initiators of detonation, and the azide is much more effective than fulminate of mercury. The aldehyde is too sensitive to be of practical use. It was made evident that the capacity to initiate detonation, depends little, if at all, on the sensitiveness either to heat or to mechanical influences. The effectiveness of the substances as initiators was ascertained by first placing a quantity (usually 1 g.) of an insensitive explosive in a tube, gently pressing it down, then putting in a small quantity of the initiator and pressing the whole down with a pressure of 2000 kg. per sq. cm. It was finally fired

[1] Anfangsgeschwindigkeit, *see Ang.*, 1911, pp. 2089–2099.
[2] *S.S.*, 1907, pp. 181, 203, 244, and 265.

on a lead plate to see if the detonation of the explosive was complete. By varying the quantity of initiator the minimum quantity was ascertained which would bring about detonation under these conditions :

Explosive	Minimum weight of initiator (grammes)	
	Silver azide	Mercury fulminate
Gun-cotton	—	·2
Picric acid	·024	·25
Trinitro-resorcin . . .	·08	·3
Trinitro-cresol . . .	·05	·3
Trinitro-benzoic acid . .	·1	·25
Trinitro-benzene . . .	·05	·25
Trinitro-toluene . . .	·05	·25
Trinitro-xylene . . .	·025	·4

Detonators constructed on this principle are now manufactured extensively. At first picric acid was used in combination with fulminate, but now trinitro-toluene or tetranitro-methylaniline are employed. The latter is the most effective, but it is more expensive than trinitro-toluene and somewhat more sensitive. The firm of Allendorff, for instance, makes a No. 8 detonator containing 0·7 g. trinitro-toluene covered with 0·5 g. of fulminate of mercury. This is fully equal to the usual charge of 2 g. fulminate and chlorate.[1] Unfortunately, fulminate is liable to deteriorate on keeping, and with such a small quantity as 0·5 g. the decomposition of a small proportion is likely to be more harmful than when there is a larger quantity present originally. Lheure [2] found that detonators containing picric acid and fulminate were more irregular than those charged with fulminate alone.

Fulminates and azides.

In a later communication [3] Wöhler discusses other substances that may be used as initiators of detonation, especially the various azides. Those of silver, copper and lead have such high auto-acceleration that they develop their full effect even when quite unconfined, and the same applies to nitrogen iodide, which, however, is so sensitive that it is exploded by a touch. Fulminate of mercury does not produce its full effect when quite unconfined, but a thin copper capsule provides sufficient confinement. The difference in the rates of acceleration is shown by exploding a small quantity in a test-tube : fulminate of mercury does not injure the tube, whereas fulminate of silver pierces it, and azide of silver shatters it to a thousand fragments. These

[1] *S.S.*, 1907, p. 5.

[2] *P. et S.*, vol. xii., p. 134.

[3] *Ang.*, 1911, p. 2089. *See also* further communication by Wöhler and Martin, *S.S.*, 1914, p. 242 ; *Ang.*, 1914, vol. i., p. 335.

results are in accordance with the results of tests carried out to ascertain the minimum amounts required to detonate trinitro-toluene:

Mercury falminate	·25 g.
Silver fulminate	·15 g.
Lead azide	·05 g.
Silver azide	·02 g.

Lead azide is now used as a substitute for fulminate for the manufacture of detonators. As long ago as 1893 experiments with the azides of silver, lead and mercury were started at Spandau by the Prussian Government, and met with considerable success, but they were stopped in consequence of a man being killed by an explosion. Lead azide is considerably less sensitive than fulminate of mercury, provided that it be in a fine state of division, but unlike the fulminate it can be obtained in crystals of a considerable size, and these are much less stable. It is indeed a general rule that the sensitiveness to shock increases with the size of the crystals. The material is evidently in a state of great strain; the strong double refraction of the crystals of all these "initiators" confirms this. Mercuric azide, for instance, when in crystals measuring 0·6 to 0·9 mm., is not much more sensitive than mercuric fulminate, but if the crystals are allowed to grow to 3 mm. diameter, it is liable to explode spontaneously even under water. Lead azide is made by the double decomposition of sodium azide and lead acetate, and the size of the crystals of the precipitated lead azide depend on the temperature. In 1910 in Germany a man was killed in a factory by the explosion of some lead azide under water, and there have been other fatal accidents.[1]

The azides are not so brisant as the fulminates. It is possible to combine the high acceleration of the former with the brisance of the latter by the use of a combined charge. Thus fulminate of mercury to which a centigramme or less of lead azide has been added is even more effective in detonating trinitro-toluene than the azide itself. Diazo-benzene nitrate also, which is of but little use by itself as an initiator of detonation, becomes very effective by the addition of a centigramme of lead azide.

Wöhler has determined the sensitiveness of many of these substances both to temperature and to the falling weight:

	500 g. weight falling mm.	Temperature of ignition.
Mercury fulminate	75–100	200°
Siver fulminate	140	200°
Sodium fulminate	over 320	150°
Mercuric azide (crystals ·6–·9 mm.)	65	200–210°
,, azide (,, 3 mm.)	0	200–210°
Mercurous azide	200	300°

[1] *S.S.*, 1911, p. 417.

	500 gr. weight falling mm.	Temperature of ignition
Silver azide	310	300°
Cupric azide	0	—
Cuprous azide	260	200–210°
Lead azide (finely divided)	260	340–350°
,, azide (moderate crystals)	130	340–350°
Basic lead azide	280	380°
,, cupric azide	315	245°

Wöhler suggests that the basic azides may be used in cap compositions instead of fulminate. They have comparatively low accelerations, and consequently are not so liable to deform the cap or give high pressures in the fire-arm.

One of the disadvantages of fulminate of mercury is that it deteriorates on storage, especially if the temperature be high or the atmosphere moist. In Austria there is an official regulation that detonators are to be stored over fused calcium chloride.[1] Different lots of fulminate differ considerably as to their liability to deteriorate, but this matter does not appear to have been studied very much. Lead azide seems to be much more permanent. This is clearly shown by the photographs by Wöhler reproduced in Fig. 102; originally, of course, detonators of both descriptions perforated the lead plates.

A B

FIG. 102. Effect of Detonators on Lead Plates after keeping in Moist Atmosphere 200 Days

A. Charged with Lead Azide.
B. Charged with Mercury Fulminate and Potassium Chlorate.

The lead azide is generally used in conjunction with Tetryl (tetranitro-methyl-aniline) or trinitrotoluene. The latter is put into the copper capsule first and pressed down, then the azide, and over that a disc of copper with a central perforation, and the pressing is repeated. The disc, which is also used in fulminate composite detonators, is to prevent the upper layer of explosive falling out and also to protect it from moisture.[2]

Both in the design and the use of detonators it should be borne in mind that the greatest effect is produced in the direction in which the wave of detonation is travelling. The most effective part is therefore the closed end of the detonator. Care should be taken that nothing intervenes between the end of the detonator and the explosive. The end should not be filled up with a small plug of putty, for instance, and when inserting the detonator into the cartridge of explosive it should be pressed well in, so that there may be no air space beyond the end.

[1] *See S.S.*, 1909, p. 38.

[2] Neitzel, *S.S.*, 1913, p. 171.

Manufacture of Caps, Detonators, etc.

Special precautions must be observed when dealing with the very sensitive substances used for charging caps, detonators and other igniters; there is far more danger of explosion than there is with other explosives. The danger is diminished by restricting the quantities that are allowed to be present in any one building. As the amount of explosive in each cap or detonator is small, this restriction does not interfere seriously with the work. The total quantities dealt with are not small, however, for it is estimated that 100 tons of fulminate of mercury are made in Germany every year, and a single factory in Great Britain manufactures more than double this quantity. The various constituents, before mixing, are sifted through fine sieves to remove all gross gritty particles. The fulminate and the explosive mixtures are kept and transported in small boxes of papier mâché or other soft smooth material. In those buildings where quantities of a pound or more may be present *en masse*, the floors should be covered with linoleum or other soft stuff, and the workers should all wear felt slippers or only socks. The greatest cleanliness should be observed. Precautions.

The mixing and drying operations are specially dangerous. The mixing of the composition was at one time done in a very simple way by placing the ingredients on a piece of paper and then stirring them with a goose feather, or by lifting first one corner of the paper and then another. Under these conditions it was never possible to protect the worker adequately, and with such very sensitive material there is always great danger of an explosion. Now the mixing is either carried out wet, or it is done in a "jelly-bag."

The wet process of mixing has been described in detail by Hagen:[1] its essential feature is that the explosive is kept wet until the mixing is complete. As the ingredients tend to separate from one another when wet, even more than when dry, in consequence of the differences in their densities, it is necessary to incorporate with them a binding material, usually gum arabic, although Alden uses gelatine. The fulminate and other constituents are mixed together by hand in a basin with just sufficient of a 6 to 7 per cent. solution of gum arabic to wet it thoroughly. Then the mixture is granulated by pressing it through first a sieve with about 6 meshes to the inch, and then one with 15 meshes. By official order these sieves must be of hair or silk. The granulated composition is dried at a temperature of 30° to 35°; then it is sifted, and that portion is selected which passes a 50-mesh sieve and is retained by a 120: this constitutes about 60 per cent.; the remainder is returned to the granulating house, where it is moistened again and mixed with fresh composition. Wet process.

Only just enough water should be used thoroughly to moisten the mixture,

[1] *S.S.*, 1911, pp. 201, 224, 243, 265, 283, and 308.

so that when it is worked it is formed into a uniform thick mud. This is not very easy, and in spite of precautions some of the composition is liable to get dry. If it be too wet, the liquid will carry away some of the potassium chlorate and other soluble constituents. Alden overcomes this difficulty by adding alcohol, which reprecipitates the chlorate, and also the gelatine which carries down with it all matter in suspension, and so clarifies the liquid. The cap composition for the Austrian military rifle is made as follows: 540 g. of finely ground and sifted potassium chlorate are placed in a basin, and 284 c.c. of a 3 per cent. solution of gelatine are added, and they are stirred together until all lumps have been broken up. Then 210 g. of wet fulminate, containing 15 per cent. of water, are stirred in, and finally 435 g. of antimony sulphide and 140 g. glass powder. Then 500 g. of 95 to 96 per cent. spirit are poured in, and the liquid is allowed to settle. The composition is filtered off on a fine double cloth, allowed to drain, pressed down, and then squeezed out by two girls, who twist round the two ends of the cloth.

The wet process suffers under the disadvantage that the workers are constantly manipulating considerable quantities of composition, and, although the material is kept wet most of the time, ignitions are not uncommon.

At one time wet composition was loaded directly into the caps by some makers. This method had the advantage that dry composition did not have to be manipulated in bulk at all. But when it dried in the cap it formed a hard mass, which was sometimes exceptionally sensitive and led to accidents.[1] Friction tubes for ordnance are still sometimes loaded by this method, but the compositions for these generally contain no fulminate.

Dry process. Fulminate, which is always stored wet until actually required, must, of course, be dried before mixing by the dry process.

Drying. The drying is carried out in an isolated building, where the wet fulminate is spread out on soft fabric. The building is heated by means of hot-water pipes to a temperature of 30° to 35°. The drying occupies only a few hours, as the fulminate is not at all hygroscopic. Then the building is allowed to cool down: on no account should the fulminate be touched until it is quite cold, as its sensitiveness increases with the temperature.

The drying is also carried out sometimes in vacuum drying ovens.

Drum method. In some Continental factories the mixing is carried out in drums of papier mâché 40 cm. in diameter and 15 cm. thick.[2] Two of these rotate within a strong enclosure. In the first all the constituents, with the exception of the fulminate, are mixed together, soft rubber balls being added to the charge to assist the mixing. The axle is turned for a few minutes by hand from behind a protecting wall. Then the contents of the drum are emptied out through a funnel and a coarse sieve, which retains the rubber balls but allows the composition to pass through. The fulminate is then added to this, and the

[1] *See S.R.*, No. 113, para. 13.

[2] *See* Knoll, *Knallquecksilber*, p. 153.

mixing is repeated in the same way in the other drum which, however, contains no rubber balls. Each charge is about 250 g.

The " jelly-bag " method originated in France, but is now generally adopted in Great Britain also. The plant is shown in Fig. 103. The various constituents, amounting altogether to ½ lb. to 2 lb., are put into the silk bag, the fulminate last. Then the workman retires behind the screen and works the lever for about three minutes to effect the mixing. Then the lever is drawn right down, so that the bag is turned inside out, and the mixed composition falls through the leather funnel into a small box standing on the bracket just below it. Explosions have occurred in this plant occasionally, but have only done very slight damage, and the workman has always escaped injury. The machine is generally arranged, however, so that he is further removed from the explosive than is shown in the figure. Mechanical power is now often substituted for hand labour, as the mixing is then more uniform. Instead of the rubber rings soft rubber balls are used ; they are placed loose in the bag, and are separated afterwards by means of a coarse sieve. Over the top of the plant a cotton sheet should be suspended to make sure that nothing can fall into the bag. **Jelly-bag method.**

The ingredients are not mixed together very intimately, but this is no disadvantage, as the violence of the caps is thus diminished.

The charging and pressing of the caps is performed in machines such as those made by Greenwood and Batley, of Leeds. The capsules are made of copper, more rarely of brass ; they are punched out of sheet metal and pressed to the required shape. The permissible variations in dimensions are very small. They are then lacquered with varnish to prevent actual contact between the composition and the metal. The capsules are filled into a plate or " hand " which has a large number of depressions, each just large enough to take a capsule ; there may be as many as 1000 of these depressions, 40 rows of 25 each. **Charging.**

The charging machine consists essentially of several brass or bronze plates, each perforated with a number of holes corresponding to the depressions in the " hand." The holes in the top plate are just large enough to take the quantity of composition required for one cap.

A little more than enough composition to fill all the caps is placed on the plate, and then with a piece of soft cloth or rubber the worker passes it over the plate and so fills all the holes. As the charge of each cap is only 0·3 to 0·6 grain (0·02 to 0·04 g.), the total quantity of explosive is not much more than 40 g., and the explosion of this would not do very serious damage, provided it be not allowed to spread to more composition. The stock of composition must therefore be kept in a safe place at some little distance. By a slight movement of the second plate each charge is now caused to fall into its cap. This movement is produced by means of a long rod, so that the worker is not near the explosive.

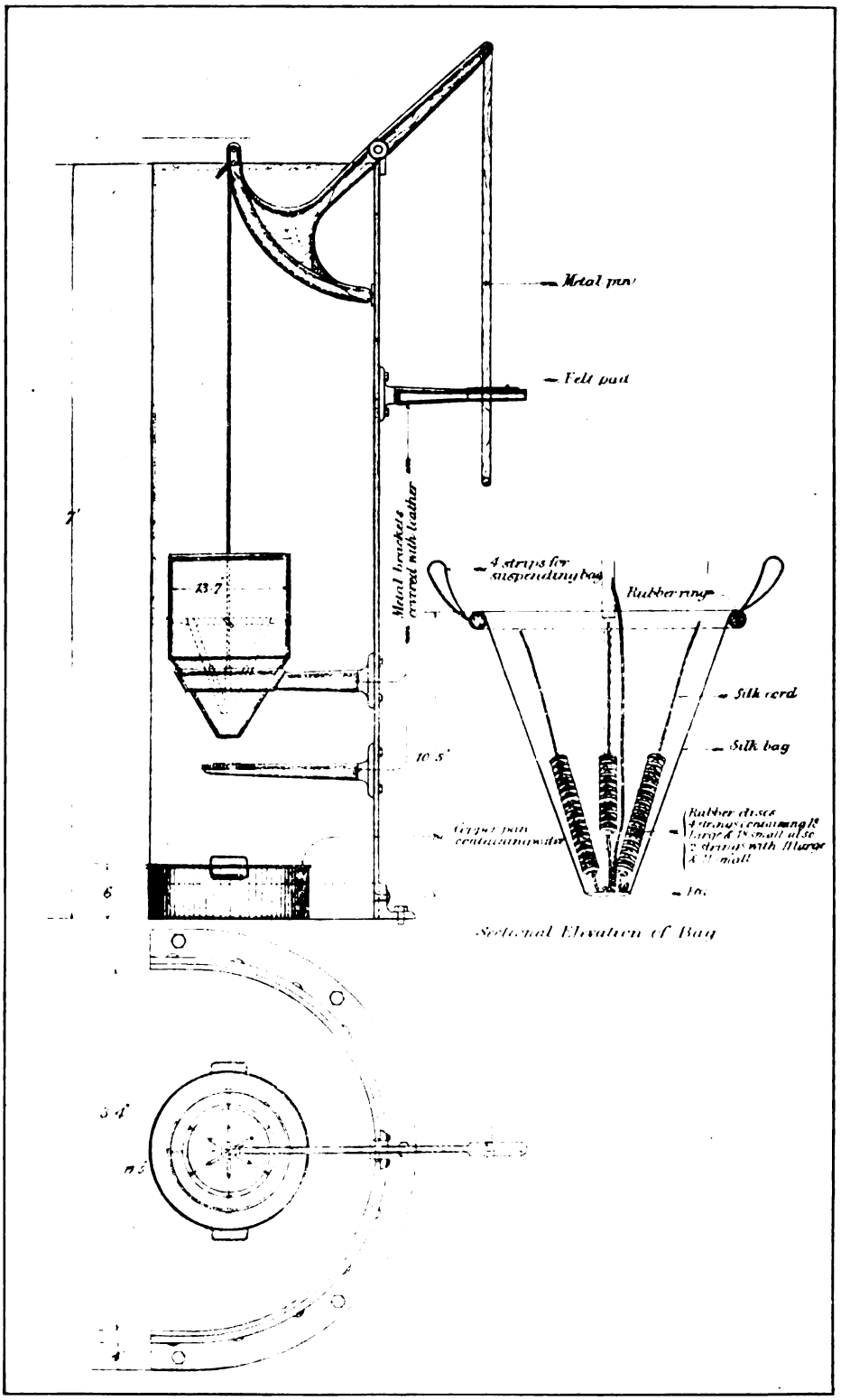

FIG. 103. Jelly-bag Plant for Mixing Fulminate Compositions

The charges have next to be pressed. This is carried out in a machine which has a row of pistons, that are made to descend on to the caps. Each piston is weighted with a separate weight, connected to it through a system of levers so that not more than a certain pressure, say 2 cwt., can be exerted on each cap. When one row of caps has been pressed, the hand moves forward automatically so as to bring the next row under the pistons.[1] **Pressing.**

Any loose composition is now removed by exposing the caps to a mild blast of air in a special cupboard, which should be so arranged that the composition carried away by the air is caused to fall into a pan of water. Then the composition is varnished. This operation is performed in an apparatus which has a number of pins projecting vertically downwards from a movable horizontal plate, one pin for each cap in a hand. The plate is brought down until the pins dip into a shallow trough containing a solution of shellac in spirit. Then it is raised again and a hand of caps is slipped under it, and it is brought down again so that a small drop of the varnish is deposited in each cap. The caps are then removed from the hand and dried at a gentle heat to remove the alcohol, and finally they are drummed or "rumbled" in order to clean them. They are then ready to insert into the cartridge cases. **Varnishing.**

The composition in each cap is frequently covered over with a small disc of tin-foil. This is essential if the caps are not to be loaded into cartridge cases in the same factory, because otherwise there is danger of some of the composition escaping. Not only would this make the caps unreliable, but the loose composition would render them liable to explode in bulk. There are two ways in which the tin-foil may be introduced. One way is to stamp the foil from a sheet straight into the caps in a special machine. In the other method a lot of discs of foil are placed in a tray, down on to which is brought a plate bearing a number of little vertical tubes. A vacuum is applied to these so that each picks up a disc. The hand is then slipped under it, the plate is again brought down, the vacuum is released, and so a piece of foil is introduced into each cap. The caps are then pressed again and varnished.

An alternative scheme of working is as follows : [2] The composition receives a preliminary pressing, the excess of composition is blown off, and foil having still moist varnish on its under side, is stamped straight into the caps, which then receive their final pressing. This method is used when the composition has binding material incorporated with it by the wet process. Finally the caps are drummed and sifted so as to remove all loose composition.

During and between all the operations careful supervision is necessary to make sure that no defective caps pass through the process, for a missfire **Inspection.**

[1] *See also* Hagen, *S.S.*, 1912, pp. 277, 297, 322, 343, 367, 388, 411, 431, and 449.

[2] *See* Knoll, *Knallquecksilber.*

is always annoying and may be dangerous, and irregularity in the charges of the caps leads to unevenness in the ballistics of the cartridges.

When used in rifles foiled caps are liable to cause fouling of the rifling, unless there be sufficient excess of oxygen in the composition to oxidize the metal of the foil completely. The effect produced by the cap depends upon many circumstances: the nature of the powder, the nature and quantity of the composition, and the way in which it has been mixed and pressed, the shape and size of the cap chamber and the anvil on to which the cap is knocked by the blow of the hammer or bolt, and the size of the fire-holes through which the products of the cap impinge on to the powder. All these factors combine together to cause the more or less rapid ignition of the powder, and consequently it is not possible to specify any one composition as the best under all circumstances. Mixtures of fulminate, potassium chlorate and antimony sulphide are used almost exclusively, although there are serious objections to all three substances. The fulminate is dangerous and expensive; it deteriorates on keeping, especially when moist, and on explosion it gives metallic mercury, which injures the brass of the cartridge case, so that it cannot be used again for the same purpose. The antimony from the sulphide is also very injurious to the brass, and the chlorate forms chlorides, which cause the barrel to rust, unless it is cleaned thoroughly after firing. There are many other mixtures that can be employed, but apparently none of them is sufficiently reliable and satisfactory for general use. Of the oxidizing agents available, saltpetre cannot be used because it is too hygroscopic, but it is not easy to see why barium nitrate cannot be substituted for potassium chlorate. As combustibles the following have been used or proposed: lead ferrocyanide, copper ammonium thiosulphate,[1] lead sulphocyanide, mercury sulphocyanide, metallic aluminium, sulphur. As substitutes for the fulminate, Wöhler has proposed the use of basic azides. Use has, however, sometimes been made of mixtures containing no substance which is explosive by itself. The United States, for instance, use for their small-arms a mixture of potassium chlorate 47·2 per cent., antimony sulphide 30·8 per cent., sulphur 22 per cent.

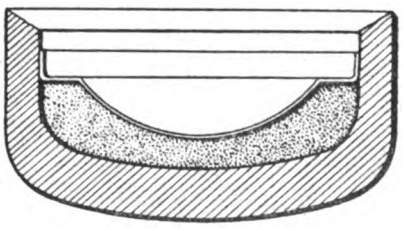

FIG. 104. Percussion Cap for Cartridge of Mannlicher Rifle
Magnified 10 Diameters

The following are some fulminate compositions that are used:

[1] *See* Herz, *S.S.*, 1912, p. 284.

	Austrian (Hagen)		English Small-Arms	
	Small-arm	Shot-gun	Gunpowder	Cordite
Mercury fulminate	13·7	33·9	37·5	19·0
Potassium chlorate	41·5	21·6	37·5	33·3
Antimony sulphide	33·4	—	25·0	42·9
Glass powder	10·7	43·2	—	—
Gelatine	0·7	1·3	—	—
Sulphur	—	—	—	2·4
Mealed powder	—	—	—	2·4

The proportion of glass in the second mixture is very large; in England compositions for shot-gun caps often contain no glass powder.

The products of explosion of a composition should contain a considerable proportion of non-volatile solids, so that a high temperature may be produced combined with a low pressure.

Official definition.

According to the ruling of H.M. Chief Inspector of Explosives, percussion caps must be of such strength and construction that the ignition of one will not ignite the others. Each cap must not contain more than 0·5 grain of composition (0·032 g.), which must be protected by a coating of tin-foil or other material approved by the Inspector, and it must not contain the anvil. If the proportion of fulminate in the composition does not exceed 25 per cent., the charge may be increased to 0·6 grain (0·039 g.). If these conditions are not fulfilled, the cap is considered to be a detonator, and must be packed and stored accordingly.

Testing caps.

An old and simple method of testing percussion caps consists in flashing them against a piece of white paper from a fixed distance and comparing the marks made. This only affords a rough indication of the uniformity of manufacture. The pressure generated may be measured in the apparatus made by Cogswell and Harrison.[1] The cartridge case is screwed down on to a hollow steel rod, inside which works a piston. The other end of this piston bears against a small lead crusher. The cap is fired by dropping a weight from a known distance on to a striker. The pressure generated by the cap is then communicated to the piston, and the consequent diminution in the length of the lead cylinder affords a measure of the pressure. The same instrument can also be used to determine the energy of blow necessary to fire the caps properly. Brownsdon [2] has given a number of methods for examining caps. The flash may be photographed, and the results are often instructive. The volume of gas generated can be measured by firing the cap in a closed chamber,

[1] *See* Guttmann, *Manufacture*, vol. ii., p. 369.

[2] *J.S.C.I.*, 1905, p. 381.

and at the same time an indication of the amount of heat liberated can be obtained by having a delicate thermometer projecting into the chamber, and reading the rise of temperature. The time of flash was estimated by flashing caps towards a rotating disc pierced with a number of holes, behind which was a camera focussed on to the disc. From the length of the marks made by the illuminated holes, and the known velocity of rotation, the duration of the flash could be calculated : it was estimated to be about 1/3000th of a second.

The methods have been further developed by Borland.[1] He estimates the length and duration of flash by firing a cap in front of a slit behind which a photographic plate is revolved, thus obtaining a V-shaped image. The heat generated he measures by firing against a thermocouple, instead of a thermometer. The temperature of the flash was measured directly, by means of an optical pyrometer, from the intensity of light in a selected portion of the spectrum. The temperatures recorded ranged from 1150° to 1520°, but when the caps were coated with aluminium powder temperatures of 1570° and 1690° were obtained. The temperatures as calculated with the aid of Mallard and Le Chatelier's specific heats were about twice as high, but in these calculations no allowance was made for heat lost by radiation and conduction and by the work done in the expansion of the gases. The results obtained with the optical pyrometer were found to be unaffected by considerable variations in the quantity of composition in the cap. An indication of the temperature can also be obtained by exposing portions of the same photographic plate to the flashes from different caps, and comparing the densities of the developed plates in a Chapman-Jones plate tester.

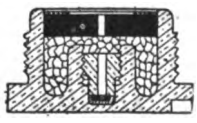

FIG. 105.
Percussion Primer for Quick-firing Ammunition

Percussion primers.

For the percussion primers of quick-firing gun ammunition the conditions are somewhat different. First, there is more force available, and consequently the composition need not be so sensitive ; and, secondly, the flash is not required to ignite the powder charge directly, but is first communicated to a small quantity of small grain black powder, which in turn ignites the cartridge ; consequently these caps do not require to be so uniform in their effects as those used for small-arms. The compositions generally contain no fulminate, but consist principally of potassium chlorate and antimony sulphide. Fig. 105 shows the construction of a German percussion primer. The percussion cap is held in place by the screwed anvil, through which there is a perforation permitting the flash to ignite some fine grain powder. Over this there is a pellet of compressed powder, also with a central perforation, held in position by a disc of shirting and a brass plate with fire-hole, held

[1] *J.S.C.I.*, 1906, p. 241.

down by the turned-over edge of the primer. After it has been assembled the primer is varnished.

Friction tubes.

The friction tubes for igniting gun cartridges that are not enclosed in metal cases are constructed on much the same principle, except that the pellet of composition is ignited by the friction of a bar or wire pulled or pushed through it, instead of by the blow of a striker or bolt. As the tube has to be inserted through a hole in the wall of the gun, it must be several inches long. The tube is filled with powder grains or pellets, which carry the flash well into the chamber of the gun. At the top of the tube is the pellet of composition, which is made of a mixture similar to that used for the percussion primers. Hagen gives the following figures for the composition used in friction tubes :

Potassium chlorate . . .	66·2 per cent.
Antimony sulphide . . .	33·1 „
Gum arabic	0·7 „

Half of the chlorate is only coarsely ground.

Electric tubes.

Naval guns and guns of position are often fired electrically. For this purpose tubes are used in which the friction pellet is replaced by some priming composition, consisting of a mixture of mealed powder and gun-cotton dust, or other easily ignited material. Through this passes a short piece of fine platinum wire, the two ends of which are connected with two copper wires, which can be joined to the poles of a battery. The general construction of the electric tube resembles that of an electric detonator, except that the fulminate is replaced by black powder, and the tube is more solidly constructed. All igniting tubes, whether friction or electric, must be so designed that the powder gases cannot blow out through the outer end.

Igniters.

The flame from the tube does not suffice, however, to ignite the cartridge, which consequently has to be provided with an igniter. This generally consists of fine grain black powder contained in a bag or pocket covering the end of the cartridge. The quantity is generally from $\frac{1}{2}$ to 2 per cent. of the weight of the smokeless powder. There are various objections to the use of black powder for this purpose, and attempts have been made to find some other material that may be substituted for it. One objection is that this priming considerably increases the amount of smoke that is formed when the charge is fired. For guns of small calibre ungelatinized gun-cotton in the form of yarn is sometimes used, but no priming gives such regular ballistics as the black powder, especially in the big guns.

Detonators or Blasting Caps

Detonators are manufactured in much the same way as percussion caps, but in consequence of the greater violence of the charge, and the far greater quantity in each, much more stringent precautions must be taken for the protection of the workers. The capsules are drawn copper tubes without joint, closed at one end. Of these 100 are placed in holes in a plate or "jig," which is often made of ebonite, the holes being lined with brass to prevent deformation. The capsules should fit the holes well but not tightly. Over this jig is placed another plate with the same number of holes, the thickness of the plate being such that each hole will just take the requisite quantity of fulminate loosely packed to charge one detonator. This upper plate slides over the jig so that the holes can be brought opposite to those in the latter. At first, however, the upper plate is placed so that the holes do not communicate. Dry fulminate, or fulminate mixture, is placed on the top plate in quantity rather more than sufficient to fill the 100 detonators, and is then gently swept into the holes; then the upper plate is slid over so that the fulminate falls into the capsules. These operations are carried out from behind a strong shield by means of rods passing through it, so that if the fulminate explodes, the worker will not be injured. The upper plate is then removed, and the surface of the jig is gently wiped down with a damp cloth to remove any loose explosive. The jig is then taken to the press, which has 100 small pistons fitting closely but not tightly into the capsules. The pressure applied to the fulminate is usually about 250 kg. per sq. cm. or 50 to 60 kg. on each detonator, which compresses the explosive to a density of about 2·2. If the density be raised by increasing the compression, the fulminate becomes less sensitive, and consequently a larger quantity burns away before detonation sets in, so that although the brisance of the detonating portion is greater, the effectiveness of the whole detonator may be less. The variation of the density and of the power with the pressure were determined by Wöhler and Matter by exploding charges of 2 g. in lead blocks : [1]

Pressure kg/cm²	Density	Trauzl test c.c.
100	1·92	30·6
400	2·56	28·5
800	2·98	26·0
1200	3·21	25·6
1600	3·23	25·4
2000	3·36	25·6

There is, of course, no direct connexion between the results of the Trauzl test and the effectiveness of a detonator, but the figures show how increase of

[1] *S.S.*, 1907, p. 245.

density can have a bad effect. After pressing, the detonators are removed from the jig either by tipping it over into a pan containing sawdust, or by pushing them out from below. Then they are drummed, or "rumbled," and sifted, to remove the sawdust and all loose fulminate. During these operations also, the workers must be protected by strong shields.

Finally they are packed in tin boxes, each of which contains not more than 100. The boxes must be lined with paper or similar material, and there must be a pad of felt, cotton wool or other soft stuff against the ends of the detonators. The spaces between the detonators and in their open ends are filled with sawdust. These boxes are then packed in an outer package. If the number of detonators within the outer package exceed 1000, there must be a double outer package with a space of 3 inches everywhere between the two. If the number exceed 5000 the outer package must have handles to assist the moving. The maximum allowed in one outer package is 10,000.[1] **Packing.**

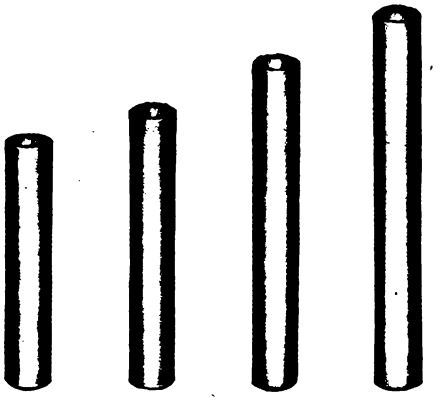

FIG. 106. Detonators

Detonators of different strengths are distinguished by numbers, which are the same in all countries :

No	Usual external dimensions of tube		Charge g.
	Length mm.	Diam. mm.	
1	16	5·5	0·3
2	22	5·5	0·4
3	26	5·5	0·54
4	28	6	0·65
5	30–32	6	0·8
6	35	6	1·0
7	40–45	6	1·5
8	50–55	6–7	2·0
9	—	—	2·5
10	—	—	3·0

The numbers in common use are 5 to 8.

[1] Explosives Act.

As regards the composition of the charge, in France fulminate of mercury only is used, but in other countries it is generally mixed with chlorate of potash up to 25 per cent. The total energy is thereby increased, as the carbon is converted into dioxide instead of monoxide :

$$Hg(CNO)_2 = Hg + N_2 + 2CO$$
$$3Hg(CNO)_2 + 2KClO_3 = 3Hg + 3N_2 + 6CO_2 + 2KCl.$$

The theoretical proportion for complete oxidation is 77·7 of fulminate to 22·3 of chlorate : in practice 15 to 20 per cent. of chlorate is generally used. A further advantage of the addition of the chlorate is that it causes the charge to run better in the loading machines. On the other hand it diminishes the acceleration of explosion and the density, and causes the detonators to deteriorate somewhat more rapidly ; the results also are not so regular.[1] In some works the fulminate is pulverized by grinding it wet with a wooden pestle. By this the mechanical sensitiveness is decreased and the acceleration is increased, and so a double advantage is obtained, but the grinding operation is a troublesome and somewhat dangerous one. Detonators with composite charges are made up so that they shall be as strong as those of the corresponding number containing only a mixture of fulminate and chlorate. The following are some of the composite charges that are in use :

No.	Trinitro-toluene or tetranitro-methylaniline	Fulminate of mercury
5	0·3 g.	0·3 g.
6	0·4 g.	0·4 g.
7	0·75 g.	0·5 g.
8	0·9 g.	0·5 g.

Precautions. In spite of every care explosions occur from time to time with such sensitive substances as fulminate, and in order to prevent widespread disaster it is necessary to restrict the quantities that may be present in any one place, and to separate the different working places and operations, so that an explosion at one spot may not cause other explosions. The German regulations lay down the following limits :

	Limit of explosive
1. Drying house and magazine for dry mixture	
(*a*) With a minimum distance of 10 m.	50 kg.
(*b*) „ „ „ 15 m.	75 „
(*c*) Vacuum drying oven	0·5 „
2. Charge in press for wet mercury fulminate and wet composition	3 „

[1] *P. et S.*, vol. 12, p. 134.

	Limit of explosive	
3. Mixing, corning, or sifting house for dry composition	10	kg.
4. Charge of the mixing, corning, or sifting appliances for dry composition	5	,,
5. Charging compartment for detonators	1	,,
6. Charging compartment for percussion caps		
(*a*) Machine charging with loading machine separate	500	g.
(*b*) ,, ,, with loading machine not separate	100	,,
(*c*) Hand charging with separate filling room	100	,,
(*d*) ,, ,, without separate filling room	30	,,
(*e*) ,, ,, protected with shield	500	,,
(*f*) Contents of transport case	1500	,,
7. Store for detonators	1000	kg.
8. Concrete magazine for detonators	3000	,,

The greatest care should be taken not only to remove from the range of any possible explosion, any composition or finished caps or detonators not actually required for the work in hand, but also to clean up at frequent intervals any composition that may be spilt or blown about. Accidents have been caused by workpeople treading on spilt composition or detonators.

Disposal of waste.

The disposal of waste composition and articles containing it is a matter of importance and some difficulty. The German regulations lay down that mother liquors from the fulminate, as well as all wash waters and residues, must be deprived of their explosibility before they are run to waste. It is recommended that this be done by boiling the strongly acid liquid for four or five hours in vessels of earthenware or wood by means of steam-coils or live steam. Alkali should not be added, as it is liable to lead to the formation of dangerous intermediate compounds. Moistened waste composition may be destroyed in the same way, or it may be stirred with a mixture of 3 parts of hydrochloric acid and 1 part of nitric acid until the fulminate of mercury has been entirely destroyed. When the vessel is emptied, the solid residue should be collected on a filter cloth, or the liquid should be drawn off by means of a cock so placed that only liquid can escape by it. The liquid should be neutralized with lime before it is run to waste. The solid residue should be tested as to its explosibility, and the boiling should be continued until it is inexplosive.

Filter cloths, sponges, etc., should be kept under water and put into a fire whilst still wet. Sawdust, which has been in contact with composition, should be destroyed in the same way.

Waste detonators and caps are to be kept in sawdust and destroyed by burning at least once a week. In the case of detonators, the burning place should be protected.

The English Inspectors of Explosives, on the other hand, recommend that detonators be destroyed by dissolving them entirely in a mixture of 2 parts concentrated hydrochloric acid and 1 part water.

Loose composition or fulminate can be destroyed very rapidly by stirring

it with a solution of sodium thiosulphate in excess, but the liquid should be kept acid by the addition of hydrochloric acid. Large accumulations of explosive waste should be avoided.

If large numbers of waste detonators have to be destroyed, they may be tied together in bundles of 50 or 100 with an electric detonator in the middle, and the whole bundle can be detonated at one time. The explosion should be carried out in a suitable pit, and the men should be properly protected.

Testing detonators.

The strengths of detonators can be compared by firing them in contact with lead plates, on which they are either laid or stood vertically.[1] Or they may be detonated in small lead blocks, as in the Trauzl test. Another method is to ascertain their power of detonating an insensitive explosive; by means of the Trauzl test or by determining its velocity of detonation it is possible to make certain whether the detonation has been complete. The U.S. Bureau of Mines has adopted a test in which the effect of the detonator on a 4-inch wire nail is measured:[2] the detonator is attached to the nail so that the bottom end is $1\frac{3}{4}$ inches from the face of the head of the nail. The nail and the detonator are parallel to one another and separated from one another by two 22-gauge (0·025 inch) copper wires that are wrapped round the detonator. The nail is fastened to the detonator by a single strand of the same wire round the middle of the detonator. When the detonator is fired the nail is bent and projected upwards: the angle to which it is bent is a measure of the strength of the detonator. The nails should, of course, be uniform in quality and dimensions. F. Martin compares the brisance of detonators by observing their effects on sensitive flames.[3]

[1] *See* Fig. 102.

[2] *See Bureau of Mines Bulletin,* No. 59; "Investigations of Detonators and Electric Detonators."

[3] *C. Z.*, vol. xxxvii, 1913, p. 90.