

EXPLOSIVES AND DETONATORS

An explosive is a solid or a liquid substance, or mixture of substances, containing a large store of chemical energy and capable of being converted by chemical action into a large volume of gases at high temperature and pressure. It differs from a mere combustible substance in that it contains, within its own composition, all the oxygen necessary for complete combustion so that the rate at which the chemical reaction occurs is far more rapid. The disruptive strength of an explosive depends on the speed with which its chemical energy is released.

LOW AND HIGH EXPLOSIVES

The terms "low" and "high" here have rather a special meaning. **A low explosive, of which, gunpowder is the typical example, consists of a finely ground mechanical mixture** of combustible (but non-explosive) substances and suppliers of oxygen. Its characteristics are that (i) it is fired by simple ignition; (2) **its decomposition proceeds by progressive combustion from grain to grain**; (3) the pressure of the gases increases gradually to some maximum, depending on the degree of confinement of the explosive; and (4) it produces a rending or heaving effect on the material on which it acts.

By contrast, **a high explosive is an explosive chemical compound** (although often mechanically mixed with combustibles, suppliers of oxygen and other substances to modify its effect) **capable of almost instant conversion to the gaseous form**. Its characteristics are that (i) it is fired, not by ignition, but by detonation or shock; (2) chemical decomposition proceeds at very high speed; (3) the maximum pressure is reached almost at once; and (4) it produces a shattering or brisant effect on the surrounding material, although this may be modified by suitable changes in composition and texture. The speed at which the explosion wave travels through a high explosive is called **the velocity of detonation** and ranges from about 1800 metres per second in some low-density powder explosives to more than 5000 metres per second in explosives of the gelatinous nitro-glycerine type.

GUNPOWDER

The composition of gunpowder varies in different countries but usually lies within the range of 12% to 20% **charcoal** (combustible); 10% to 20% **sulphur** (combustible); and 60% to 75% **potassium nitrate or saltpetre** (an oxidising agent). In Britain, the usual composition is 15% charcoal, 10% sulphur, and 75% potassium nitrate.

The normal method of firing gunpowder is by means of a **safety fuse** which simply consists of a core of fine-grained gunpowder enclosed within a covering of cotton thread, tape, or gutta-percha. For use, one end of the fuse is freshly cut and placed in the powder, the other end being ignited by a naked light or an enclosed igniter. **The fuse burns at the rate of two feet per minute**, or go-seconds per yard.

The advantages of gunpowder are that it is cheap, safe to handle, and stable. Its rending effect makes it suitable where it is undesirable to pulverize the mineral worked. **Its disadvantages** are that it is spoilt by water, it is bulky for a given explosive effect and—most important from the coal mining point of view—**its flame is of long duration** and a portion of the explosive may continue to burn after the coal or stone has been brought down, so exposing the burning residue to the external atmosphere. It is therefore **dangerous in any place where there is risk of inflammable gas** and it has been replaced for nearly all coal-mining purposes by some form of high explosive. **All explosives on the Permitted List are of the high-explosive type.**

HIGH EXPLOSIVES

Nearly all high explosive compounds are "**substitution products**" of a few well-known **combustible substances** such as (a) **cellulose** ($C_6 H_{12} O_5$); (b) **benzene** ($C_6 H_6$); (c) **glycerine** ($C_3 H_5 (OH)_3$); and (d) **ammonium** (NH_4) although the latter never occurs in the free state. By "substitution product" is meant the new chemical compound formed when one atom (or, in certain cases, a group of atoms, termed a "radical") in the original compound is replaced by another atom or radical. In nearly all cases, **the new substitution products are obtained by acting on the original compound with nitric acid, HNO_3** . In other words, when the combustibles mentioned are treated with nitric acid, the resulting product is a high explosive compound. Let us deal briefly with each of the foregoing types in turn.

(a) Cellulose compounds

Cellulose is the "colourless material of the woody[^] fibre of plants." It has the same atomic composition as starch and gum, but as its properties differ from theirs, we must suppose that the atomic arrangement differs in these various "isomeric" compounds, as they are called. **When treated with nitric acid**, cellulose is converted to some form of **nitro-cellulose, or nitro-cotton**, depending on the degree of nitration. Two of the forms are guncotton and collodion cotton.

Guncotton is a highly nitrated form of nitro-cellulose containing more than 12-3% nitrogen. In the dry state, it is sensitive to friction and concussion and must be handled with care. It is not suitable for mining requirements.

Collodion cotton contains 10% to 12-3% nitrogen. It is soluble in a mixture of alcohol and ether and is therefore called "soluble" nitro-cotton. When the solvent is evaporated off, the nitro-cotton remains as a glue-like mass which is more stable and safer to handle than the original explosive. This treatment is known as **gelatinisation**. Collodion cottons are also **soluble in nitroglycerine** and then help to form such gelatinised explosives as blasting gelatine, gelignite, and many permitted explosives. Such explosives have a high density and are very resistant to the action of water.

(b) Benzene compounds

Benzene or benzol, C_6H_6 , is a colourless inflammable liquid obtained by distilling coal tar. Associated with it are two other substances **toluol** and **phenol** (carbolic acid) which may be regarded as combustible substitution products of benzene. All three compounds may be acted upon by nitric acid to produce high explosive compounds of which **nitro-benzene**, **trinitrotoluene** (T.N.T.) and **trinitrophenol** (picric acid) are examples.

(c) Glycerine compounds

Glycerine, or glycerol, $C_3H_5(OH)_3$, is a thick colourless liquid with a sweet syrupy taste, obtained by the decomposition of fats and oils in the process of making soap and candles. When glycerine is treated with nitric acid, the result is **nitroglycerine** = $C_3H_5(NO_3)_3$. This, in its pure state, is an oily fluid, so sensitive to explosion by shock of any kind that it is altogether too dangerous to be handled except by an expert. Its temperature of detonation is also very high, about $5700^\circ F$. When placed on the skin, it is slowly absorbed causing a violent headache. To render it suitable for industrial use, it must either be absorbed by some inert material, as in dynamite, or be gelatinised by treatment with collodion cotton, as in blasting gelatine and gelignite.

Dynamite is essentially a mixture of 40% to 75% nitroglycerine (N-G) with an absorbent earth called kieselguhr (95% silica). It has the disadvantage that, when it comes into contact with water, the latter displaces the N-G, so increasing the danger of accidental ignition. Dynamite is little used in mining work.

The chief types of non-permitted gelatinous nitroglycerine explosives are:—

(1) **Blasting gelatine**, consisting of about 93% to 95% N-G and 7% to 5% **collodion cotton**. It is the strongest of all known blasting explosives and is much used in gold mining and in the hardest rocks such as quartzite and haematite. It is very resistive to the action of water.

(2) **Gelatine dynamite**, composed of 80% **blasting gelatine** (as above), the remainder being an admixture of **wood meal** (a combustible) and **potassium nitrate**, or sodium nitrate (acting as an oxidising agent). A little **calcium carbonate** is added as a stabiliser to prevent decomposition of the collodion cotton. Gelatine dynamite is somewhat inferior to blasting gelatine in strength and resistance to water.

(3) **Gelignite**, composed of about 65% **blasting gelatine** (60% N-G and 5% collodion cotton) together with 7% **wood meal** and 27% **potassium (or sodium) nitrate**, the remainder being calcium carbonate and moisture. Gelignite is less violent than the two previous explosives and is an all-round non-permitted explosive for use in non-gassy coal mines, shaft sinking and quarries.

One of the disadvantages of **ordinary nitroglycerine** is that it **freezes at $46^\circ F$** and explosives containing it may explode when subject to friction or mechanical shock. At one time, when N-G explosives became frozen, it was necessary to thaw them in a special water-heated warming pan, although foolhardy persons sometimes attempted to unfreeze them in an oven or in front of a fire, with serious results. **Nowadays, all N-G explosives are of the low-freezing type**, designated variously as Polar, Arctic, or Anti-frost explosives. In these, during manufacture, some of the glycerine is replaced by ethylene glycol, $C_2H_4(OH)_2$, which is nitrated in the usual way to form **di-nitro-glycol**, $C_2H_4(NO_3)_2$. The latter does not freeze until the temperature has fallen to $-22^\circ C$ ($-8^\circ F$). Only about 15% to 20% of di-nitro-glycol is required in an explosive to render the whole immune from freezing at winter temperatures normally experienced in Great Britain.

(d) Ammonium nitrate, NH_4NO_3

Ammonium nitrate is a white crystalline solid formed by the action of nitric acid, HNO_3 , on ammonia gas, NH_3 , giving the product NH_4NO_3 . Ammonium, NH_4 , is rather interesting because it never exists alone, but only as a radical in a compound such as ammonium nitrate. The latter is even more interesting, for it is **a high explosive, an oxidising agent, and a cooling agent at one and the same time**. It is, however, **never used as an explosive by itself**, because, without admixture with some other high explosive such as nitroglycerine or trinitrotoluene to *act* as a "**sensitizer**", it is very difficult to detonate. This, of course, has the advantage of rendering it very safe to handle and transport. Other characteristics of ammonium nitrate are:—

(1) **It has a relatively low temperature of detonation** (about $2100^\circ F$ as compared with $5700^\circ F$ for nitroglycerine).

(2) **It has a surplus supply of oxygen**, so enabling it to act as an oxidising agent.

(3) **It is less violent than N—G explosives** and exerts a rending or heaving effect.

(4) **It is hygroscopic** and readily absorbs moisture, being then liable to incomplete detonation.

It must therefore be kept wrapped in water proof wrappings of waxed paper, parchment, or metallic foil. It is unsuitable for use in wet conditions where contact with water may be prolonged.

PERMITTED EXPLOSIVES

A "permitted explosive" is one which has been approved for use in gassy and dusty mines after having passed certain prescribed official tests at the Safety in Mines Research Establishment at Buxton. Permitted explosives only must be used:—

(1) Throughout any mine in which safety lamps are required in any part.

(2) In any part of a mine where safety lamps are being used as a temporary precaution.

(3) In any part of a naked light mine which is dry and dusty.

(4) In any main intake airway or in any road used for transporting coal mechanically or by gravity.

The general characteristics of a permitted explosive are that it has (a) a relatively low flame temperature or temperature of detonation; and (b) a flame of short duration, less than one-thousandth of a

second. These characteristics have been achieved in various ways which may be considered under the headings of (i) cooling agents, (2) sheathed explosives, and (3) Eq.S. explosives.

Cooling agents

All permitted explosives have a cooling agent included in their composition, **usually sodium chloride**, NaCl., which absorbs heat by its volatilisation. Potassium chloride, KCl, and sodium fluoride, NaF, have a similar action. Ammonium Chloride, NH_4Cl , liberates ammonia which evaporates and absorbs heat in so doing. Calcium Chloride, $\text{CaCl}_2 + 6 \text{H}_2\text{O}$, and Borax, $\text{Na}_2\text{B}_4\text{O}_7 + 10\text{H}_2\text{O}$ contain water of crystallisation which is set free by the action of heat.

Sheathed explosives

As an additional safeguard, **each cartridge is surrounded lengthwise by a sheath of sodium bicarbonate**, NaHCO_3 , about one-eighth inch thick, the **ends** of the cartridge being left uncovered. The NaHCO_3 is normally in powder form held in position by a paper wrapper, although felt sheathing has been used and later abandoned because of difficulties in manufacture.

The purpose of the sheath is to reduce the risk of igniting gas, especially in a break which intersects, or is adjacent to a shothole. It acts **by forming an extingutive blanket of CO_2 and water vapour** around the flame and hot gases from the explosive. It protects the charge along its whole length, except the inner end which must be protected by a clay plug, and the outer end which is protected by the normal stemming.

A serious disadvantage of the sheath is that it may be **removed or displaced** by accident or design and then fails to achieve its purpose. Moreover, some of the sheathing material may become lodged between successive cartridges, so preventing the transmission of detonation from one to another. The cartridges must be handled with care.

Eq. S. Explosives (Equivalent to sheathed)

An Eq. S. explosive is one without a sheath which is "certified to be not less safe than an equivalent sheathed explosive of the same group," the **inert material being incorporated direct and uniformly into the explosive composition itself**. This removes the dangers arising from a displaced sheath and simplifies manufacture. The inert material may be sodium chloride used in conjunction with ammonium nitrate, or, alternatively, ammonium chloride used in conjunction with sodium nitrate.

It should be noted that the nominal weight of a **sheathed** explosive cartridge is the weight of actual explosive (excluding the sheath) although the specified diameter includes the sheath. On the other hand, the weight of an Eq.S. cartridge of similar diameter and strength is the whole weight of the cartridge and is about one-third greater than the nominal weight of the corresponding sheathed explosive. Thus, to give the same blasting effect, an increased nominal weight of Eq.S. explosive will be required.

Types of Permitted Explosive

(1) **Gelatinised nitroglycerine explosives**, containing up to about 40% N-G and nitroglycol gelatinised with nitro-cotton, together with some ammonium nitrate, a cooling agent (usually sodium chloride), a combustible (wood meal or oat husk meal) and small percentages of other minor ingredients. Such explosives have **high water resistance and high density** (S.G. about 1-5), giving great concentration of explosive energy. They are used for heavy duty in stone drifts, sinking shafts, and hard rippings. Examples are Polar Ajax, Nitrox No. 2, and Driftex, all of which may be sheathed or unsheathed. Unigel, Pentregel, and Denespex are Eq. S. explosives of this type.

(2) **Powdery nitroglycerine explosives**, containing up to about 18 %N-G and nitroglycol, with or without nitro-cotton and from 25% to 50% ammonium nitrate, together with sodium chloride and other ingredients as previously specified. Such explosives have a **lower density** (S.G. =about 1-0), giving a greater spread of explosive in the shothole and a **less violent blasting action** suitable for general work in medium rock and hard coal. Examples are Polar Viking and Minex, both sheathed. Eq.S. explosives of this class include Unigex, Unifrax, Lesslak, and Pencol.

(3) **Powdery non-nitroglycerine explosives**, based on ammonium nitrate (35% to 80%), -together with a **sensitizer such as T.N.T.**, plus some combustible material and a cooling agent, as before. They have a S.G. ranging from 0-7 to 1-0 and a **milder and more rending action**

than the previous types and they have a wide application in coal. Examples are Unirend, Tolumite INo. *i* and Trinite No. I, all of these being Eq.S. explosives.

The normal permissible maximum charge for ordinary permitted explosives (sheathed or unsheathed) is **28 oz.**, but that for an Eq.S. explosive is **36 oz.** and certain unsheathed types (e.g. Polar Ajax) have a maximum charge of **48 oz.** when used in stone drifts.

To qualify for admission to the permitted list an explosive has to pass certain tests carried out at the Safety in Mines Research Establishment at Buxton. In these tests, certain specified weights of charge (varying with the type of explosive, whether unsheathed, sheathed, or Eq.S., and with the particular test being carried out) are fired, both with and without stemming, into a g% methane-air mixture and into a gallery containing a layer of coal dust. **Five shots are fired in each test and the explosive must not cause ignition in any of them.**

A factory test is also carried out with a ballistic pendulum to ascertain **the weight strength of the explosive, or its strength per unit weight** compared with that of blasting gelatine taken as standard (=100%). The weight strength of permitted explosives varies from 40% to 60% of that of blasting gelatine.

When the weight strength of an explosive h known, its **bulk strength or its strength per unit volume** may be calculated from its known density compared with that of blasting gelatine (S.G. = 1.5). In cases where the explosive has a S.G. of 1.5, (e.g. the high-density gelatinous explosives) its bulk strength is equal to the weight strength. It will be understood, however, that, if the explosive has a low density (say 0.75) a given weight will occupy twice the volume, and thus its bulk strength will be half its weight strength. As the density of ordinary permitted explosives varies between these limits, an explosive can be selected to give the desired effect, whether maximum concentration of explosive energy, or a spreading effect, as required.

Ultra-safe Explosives

Much attention has been devoted to the design of a permitted explosive which has a still higher factor of safety than normal Eq.S. explosives in places where firedamp is a hazard (more particularly in breaks) and which is suitable for use in coal and in roof rippings. Such an explosive must of necessity be of **low power, low density, and low velocity of detonation**, and it achieves its higher safety by having incorporated in its composition a high percentage of **very finely ground sodium chloride and nitrochalk which presents a large surface area in contact with any gas into which the explosive flame may be projected**. It will doubtless be necessary, in roof rippings, to bore more (or larger) holes and increase the weight of charge to give efficient blasting results. Nevertheless, it is considered that the overall safety factor of the blasting operation will be greatly increased and further developments in this direction are to be expected.

ELECTRIC DETONATORS

A detonator is the means whereby the requisite high-intensity mechanical shock is applied to a high explosive to initiate its detonation. Briefly, it consists of a copper tube containing the detonating compound and fitted with an electric fuse. At one time, the detonating compound consisted of 80% fulminate of mercury and 20% potassium chlorate, but this has now been replaced by the lead azide detonator which is more powerful and less likely to deteriorate in storage at high temperatures

The Lead Azide Detonator

This consists of a **copper tube**¹ about 1 ¼ in. diam. and 1 ¼ in to 2 1/8 in. long. At its lower end it contains two separate charges namely:—

(1) A **top or priming charge** consisting of a mixture of **lead azide, lead styphnate** (a binding agent which also improves sensitivity) and a small percentage of **aluminium powder** (to prevent clogging of the pressing punches during manufacture). The whole is called an A. S.A. mixture.

(2) A **bottom or main charge of P.E.T.N.** (pentaerythritol-tetra-nitrate) or alternatively of **tetryl** (trinitro-phenyl-methyl-nitramine, which is initiated by the priming charge and acts as the detonating medium.

The standard size is a No. 6 detonator containing 0-35 gm. of the A.S.A. mixture and 0-25 gm. of P.E.T.N. or tetryl, but larger sizes No. 7 and No. 8 are also made containing base charges of 0-40 gm. and 0-55 gm. respectively.

In the upper half of the tube is a **neoprene plug assembly** consisting of (a) the **leading wires**, (b) the **closing plug of neoprene** through which the leading wires pass, and (c) the **electric fuse-head** which may be of either the low-tension or the high-tension type although the L.T. detonator is now standard in British coal mines. It is distinguished by having two white leads, whilst H.T. detonators have one red and one white lead.

The **leading wires** are normally of tinned iron up to 72 in. long, and tinned copper beyond that length. They may be double cotton covered and waxed for use in dry surroundings; or plastic covered for wet conditions; or enamelled, cotton covered and waxed for use under water. The sealing plug is made of **neoprene** which is a synthetic rubber material impervious to water and oil and permanently rendering the detonator tube air-tight and water-proof.

Low-tension Fuse

This is shown enlarged in Fig. 2 (a). It consists of two thin strips of **brass foil** separated by a sheet of insulating press-board and connected diagonally at the lower end by fine **wire bridge** of nickel chromium alloy which is immersed in a bead of ignition compression. The leading wires are soldered to the brass foils at the upper end so that there is a **continuous metallic circuit through the fuse**.

The **bead or globule** around the tip of the fuse head is made up of several layers, namely (a) an inner sensitive igniting compound surrounding the wire bridge and consisting of lead mono-nitro-resorcinate (L. M.N.R.) mixed with potassium chlorate and a little nitro-cellulose; (b) a second layer consisting of charcoal and potassium

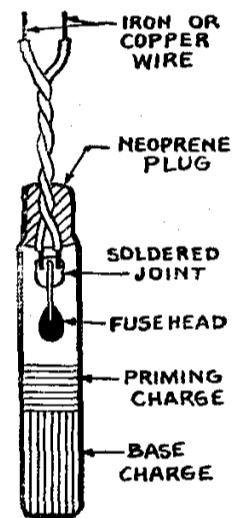
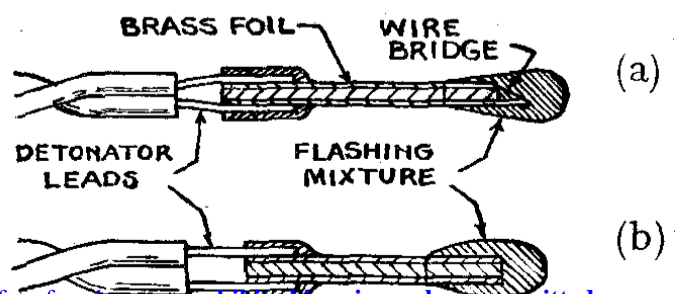


Fig. 1.
Lead Azide
Detonator.

¹ Aluminium casings may be used for plain detonators fired by safety fuse but are **prohibited in mines where permitted explosives are required to be used** because of the danger of igniting firedamp. On the other hand, a copper cased detonator is normally incapable of igniting firedamp, even when exploded in the open in the most inflammable mixture of firedamp and air. In a plain detonator, the upper part of the casing is filled with sawdust which, must be carefully removed, before the fuse is inserted. The latter is held in position by crimping the open end of the detonator around it).

chlorate to give a hot flash of flame; and (c) an outer layer of nitro-cellulose to bind the whole together.

High-Tension Fuse

This differs from the L.T. type in that there is **no metallic bridge** and the brass foils are of equal length. Moreover, the innermost sensitive igniting layer in this case consists of copper acetylide mixed with finely divided graphite to form a semi-conducting medium or chemical bridge, through and across which the electric current sparks when a sufficiently high E.M.F. is applied.

Voltage and current required for detonators

L.T. detonators have an internal resistance of about 1 ohm and the total resistance of an average single-shot firing circuit (say 50 yd. of twin cable) is about 7 ohms. The minimum current required to cause ignition is about 0.5 amp. this causing ignition in about 0.05 second. The minimum voltage that must be applied to such a circuit is thus $0.5 \times 7 = 3.5$ **volts**. If a number of detonators are connected in series, or if a longer cable is used, the minimum voltage must be increased accordingly. In practice, the firing current supplied is of the order of 1 ampere for single shots and 1 ½ amps or more for a number of shots connected in series.

H.T. detonators have an internal resistance which varies within wide limits, 1500 to 50,000 ohms, and is so great that the resistance of the cable and connections may be ignored so long as a complete circuit exists. The minimum igniting current is very small, but ignition of an average H.T. detonator is ensured if about **50 volts** is applied to the circuit, the current never exceeding about **0.025 amp**.

At one time, when most shots were fired singly, both H.T. and L.T. firing systems were used about equally but only L.T. detonators are now used in N.C.B. collieries. Perhaps the chief advantage of the H.T. detonator is that an increase in the length of the circuit, or badly made connections, have a negligible effect on the total resistance of the circuit and are less likely to cause failure of ignition. On the other hand, **L.T. detonators have the following points in their favour:—**

- (1) The continuance of the circuit, or even that of a single detonator, may be tested by a galvanometer, a very small current being passed, insufficient to render the metallic bridge incandescent.
- (2) L.T. detonators have an almost uniform internal resistance and firing characteristics and are therefore the only type suitable for simultaneous shot firing where all the detonators are connected in series and the same current passes through all the detonators alike.

Delay Detonators

A delay detonator resembles an ordinary L.T. instantaneous detonator in so far as the electric circuit and the priming and detonating composition are concerned, but it **differs from the instantaneous type in that a delay element is introduced between the fuse head and the priming charge**. This element consists of a copper or brass sleeve filled with some special composition which burns at a specified rate, the nature and amount of the material depending on the magnitude of the delay required. The delay element is "gasless" in that the products of combustion do not give rise to gas pressure tending to burst the detonator prematurely. All delay detonators have **copper leading wires**, usually 120 in. long.

Delay detonators are used where it is desired to fire a full round of shots in a definite sequence (e.g. in stone drifts and sinking pits) with some short pre-determined time interval between successive groups of shots. All the shots are connected up in simple series and the firing current is applied simultaneously to all of them, but the various shots are timed by their delay elements to go off at the desired intervals. A condition is that the maximum period of delay must not exceed 5 seconds in order to reduce the possibility of firedamp, released by the earlier shots in a round, being ignited by later shots.

Originally, delay detonators were issued in a series numbered 0—10, with a nominal delay period of **one second** between successive delay numbers, as shown by a tag attached to one of the leading wires, both of which were yellow. Only 4 delays could be used in any one round of shots in order to keep within the overall period of 5 seconds between first and last. Later, these were discontinued and **replaced by a series with half-second delays** over a range of 0—10 and distinguished by having one red and one yellow lead. This permitted twice the number of delays to be used within the period of 5 seconds and larger rounds to be fired in one operation, whilst increasing blasting efficiency, improving fragmentation, and reducing dust and fumes.

Short Delay Detonators (Milli-second delays)

These represent the latest development whereby **a much faster burning delay composition is used** so that the nominal delay period is measured in only milli-seconds (thousandths of a second). One type consists of a series in which the nominal delay interval is 25 **milli-seconds** (one-fortieth of a second) up to No. 4 delay, and **50 milli-seconds** (rising to 85 milli-seconds) thereafter up to No. 15 delay. Another type, known as the "Carrick" type, has a delay interval of 50 milli-seconds in a series from 0—6, whilst detonators with 20 milli-second delays are also being developed.

Perhaps the chief advantage of short-delay detonators is that **the whole round of shots is fired in a fraction of a second** (ranging from 75 milli-seconds upwards to a maximum of 0.7 second according to the number of delays used and their type) and the chance of firedamp being ignited by the last shot is therefore very remote. The blast may be regarded as being almost simultaneous. Nevertheless, the short delay periods

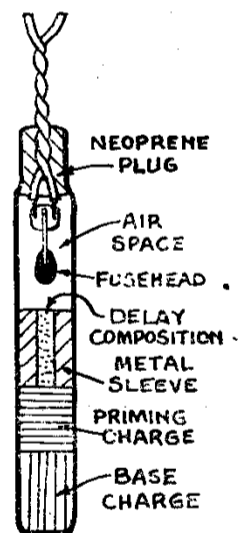


Fig. 3
Delay Detonator.

still allow rock movement to take place between the shots, so reducing the burden on each group of shots in turn, while the interval is not too long to prevent the blast from a shot reinforcing the effect of the previous one and so contributing to its effect. Short delay detonators have been used in shafts and stone drifts and, by special permission, in rippings and on coal faces.

SHOTFIRER'S TOOLS AND APPARATUS

To enable him to carry out his duties, a shotfirer requires a variety of tools and apparatus including:—

1. Flame and electric safety lamps.
2. Locked detonator case and canister of explosives.
3. Scraper and break detector, wooden stemming rod and pricker of wood, bone, or non-ferrous metal.
4. Shot firing cable and exploder.
5. Pocket knife, chalk, notebook and pencil.

The purpose of all these items will be self-evident to mining students but we would add the following notes for further guidance.

Detonator Case

This should be made of a light, but sufficiently strong material to protect the detonators from blows or damage and the interior should be lined with insulating material so that a detonator (or its leads) cannot make contact with metal outside the case. The lid of the case should lock automatically when it is placed in the fully closed position. The interior should be divided into compartments, one for each detonator, and only one type of detonator should be kept in each case. The shotfirer must retain the key in his possession throughout his shift and must not remove any detonator from the case unless it is required for immediate use.

Canisters for Explosives

The traditional method of conveying explosives into the mine is that they are issued in 5 lb canisters which are carried underground by shot firers and workmen. Such canisters must be stoutly constructed, water-tight, of convenient size and shape to hold the cartridges, and self-locking. When not in use, they must be kept in a safe place. With the approval of the Divisional Inspector, however a special scheme of transit may be instituted whereby sufficient explosives required for a period of 24 hours canisters (which may contain more than 5 lb.) and conveyed underground. The attendant at the station

Scraper and Break Detector

It is the duty of a shot firer to clean out all shot-holes and, in mines where safety lamps are required, to test each hole for breaks running along or across it. If a break exceeding one-eighth inch is found, the hole must not be charged.

A combined scraper and break detector is shown in Fig. 4. It consists of a $\frac{1}{2}$ in. brass or steel rod at least 4 $\frac{1}{2}$ ft. long (or 6 in. longer than the depth of the deepest hole to be tested) and tapering at each end to $\frac{1}{4}$ in. diam. One end is fitted with a prong or chisel edge to detect breaks whilst the other end is fitted with an eccentric semi-circular disc to act as a scraper (but not to be used for charging or stemming).

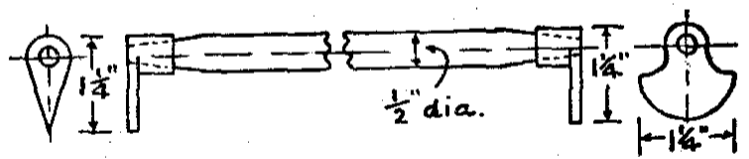


Fig. 4. Scraper and Break Detector.

Shotfiring Cables

Various designs of cable are available according to the purpose in view. These include:—

(a) **Two-core cable for single shotfiring**, each core consisting of at least four copper wires not less than 0-018 in. diam., insulated with vulcanised rubber or P.V.C. (Polyvinylchloride) 0-020 in. thick, with the two cores twisted and covered with a sheath of cotton braid, tough rubber or P.V.C.

(b) **Single-core cable for multi-shotfiring**, consisting of a conductor of at least three copper wires not less than 0-036 in. diam., insulated to withstand at least 250 volts, and further protected, against wear and damage.

(c) **Single-core cable for multi-shot firing in drifts** where unapproved, high-capacity exploders are in use. Such cables must be effectively insulated to withstand 1500 volts for a period, of 5 seconds and must be free from joints or repairs unless properly made and vulcanised.

(d) **Two-core cable for shotfiring in shafts**, each core consisting of at least seven copper wires each not less than 0-029 in. diam., insulated to withstand at least 250 volts. It must be adequately protected and capable of supporting its own weight when suspended, with a factor of safety of four.

No cable must be used for firing shots unless its length is at least (a) **20 yd.** when a single shot is being fired; (b) 50 yd. for a round of shots in coal; (c) **70 yd.** for a round of six shots or less in stone; and (d) **200 yd'**, for a round of more than six shots in stone, or any shot in a sinking pit.

Exploders

These may be divided into three groups, namely (a) single-shot, (b) approved multi-shot and, (c) larger and more powerful unapproved exploders for use in stone drifts and shaft sinking.

The single shot exploder is normally a small magneto generator operated by hand and capable of producing enough current for the brief period necessary to fire an electric detonator. It consists essentially of a permanent steel magnet between the poles of which an armature may be revolved, being actuated through gearing by a rotary handle, or by a rack and pinion. The only difference between H.T. and L.T. exploders is that **the L.T. armature winding has a smaller number of turns of thicker wire than the H.T. type**. A L.T. exploder gives a voltage ranging up to about 15 volts, (depending on the speed of operation) sufficient to cause a current of at least 0.5 amp to flow through a normal L.T. circuit. A H.T. exploder gives about 125 volts and this is sufficient to provide the very small current required by a H.T. detonator.

An important feature of an exploder is that it shall be **intrinsically safe, i.e. it must be incapable of generating a spark of sufficient intensity to ignite firedamp**, if present. It should be understood, that like all electro-magnetic apparatus, a magneto exploder possesses high inductance, and, unless precautions are taken, a high induced voltage is liable to be set up by induction as the current falls to zero after the circuit is broken, so creating a dangerous spark or break-flash. To avoid this, one of the following methods may be employed:—

(a) A continuous broad copper sleeve 0.22 in. thick is placed around the armature core to provide a short-circuited path of low resistance for eddy currents. Alternatively, layers of tin foil may be placed between the layers of the wires on the magnet winding.

(b) A non-inductive resistance is connected across the terminals of the exploder inside the casing.

(c) A condenser may be connected in the circuit.

The Derby 6-shot L.T. exploder (which is intrinsically safe) consists of a 60-volt block of dry primary cells, an electrolytic condenser, an automatic time switch, and a suitable resistance. The battery is made to charge the condenser which in turn discharges to fire the shots. In addition there is a separate testing circuit which is energised by a single 1.5 volt cell. In operating the exploder, the shots and cable are connected in series to the line terminals and, if everything is in order, a light indicator will become illuminated. The push button is then depressed to clear the indicator from the line and connect the 60 volt battery to the time switch. Thereafter, the detachable firing key is turned, so firing the shots.

The Beethoven dynamo condenser exploder is a powerful "non-approved" multi-shot exploder capable of firing up to 200 detonators connected in series and widely used, by special permission, in stone drifts and sinking shafts. A hand-driven generator is fitted to generate an a.c. voltage which, in conjunction with a step-up transformer and metal rectifiers, charges a 6 microfarad condenser to a potential of some 1200 volts d.c. A neon-lamp indicates when the condenser is charged and a button switch supplies the condenser voltage to the output terminals.

Circuit tester

Before a round of shots is fired by either instantaneous or delay detonators, the circuit must be tested for continuity and resistance by means of approved testing apparatus. One type is the **Evershed and Vignoles safety ohmmeter** which is itself quite incapable of firing a detonator. It consists of a hand-driven generator and a direct-reading ohmmeter mounted together in a plastic case, the whole weighing 3 lb. In operation, the two terminals of the firing cables are connected to two spring terminals on the instrument. The generator handle is then turned at about 160 r.p.m. and the resistance of the circuit is read directly on the scale. This may then be compared with the calculated expected resistance and will show up bad connections (giving too high a resistance) or the omission of some of the detonators from the circuit (giving too low a resistance).

TEST PAPER MK/11

1. What is the difference between a combustible substance and an explosive?
2. (a) When an explosive is fired, what change takes place which gives it its force? (b) What are the differences between a high explosive and a low explosive? (c) Give the composition of (i) gunpowder, and (ii) gelignite.
3. (a) Why is nitro-glycerine never used alone as an explosive in coal mines? (b) Why is ammonium nitrate never used alone?
4. Given that a certain explosive contains (a) nitro-glycerine, (b) nitro glycol, (c) nitrocellulose, (d) nitrate of sodium, (e) chloride of sodium, (f) wheat flour and (g) nitrate of ammonium, state the purpose of each item?
5. Sketch and describe an ordinary instantaneous detonator, explaining the differences between high-tension and low-tension detonators.
6. What type of permitted explosive do you consider to be the most suitable for use in (a) hard cross-measure drifts, (b) roof rippings, and (c) coal? Give reasons. (d) State the composition of any one of them, if known.
7. Give a list of the chief causes of accidents causing personal injury and arising out of the use of explosives in mines, apart from accidents causing ignition of gas or coal dust.

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MINE ΩOPKINΓ

Answers Lesson MK/11

EXPLOSIVES AND DETONATORS

1. What is the difference between a combustible substance and an explosive?

COMBUSTIBLES AND EXPLOSIVES

Strictly speaking, the term "explosive" includes the term "combustible" for all explosives -are combustible. On the other hand, all combustibles are not explosive. A **combustible** is any substance that will burn in air or oxygen, at whatever rate, whereas **an explosive** is one that contains within itself (or intimately mixed with it) all the oxygen for almost instant combustion. In the final analysis, it is the **rate of combustion** that determines whether a substance is to be classed as a mere combustible or as an explosive. In a substance that is merely combustible, the rate is relatively low; in a low explosive, the rate is relatively high; whilst in a high explosive, the rate is almost instantaneous.

2. (a) When an explosive is fired, what change takes place which gives it its force? (b) What are the differences between a high explosive and a low explosive? (c) Give the composition of (i) gunpowder, and (ii) gelignite.

HIGH AND LOW EXPLOSIVES

(a) Force of explosive

When an explosive is fired, a chemical reaction takes place between its constituents whereby a relatively small volume of properly confined explosive material is suddenly converted into a large volume of gases at high temperature and pressure. Chemical energy in the explosive is transformed into mechanical energy and heat.

(b) High and Low Explosives

(1) A **high** explosive is a chemical compound (often mixed with other ingredients to modify its action) which contains all, or most, of the oxygen required for its complete combustion. A low explosive is a mechanical mixture of combustible materials and separate oxidising agents.

(2) A **high** explosive must be detonated to produce its maximum effect. A low explosive is fired by ordinary ignition.

(3) In a **high** explosive, the detonative shock travels through it at velocities ranging up to 20, 000 feet per second. In a low explosive combustion proceeds from grain to grain at a relatively low rate, depending on the degree of confinement.

(c) Composition of gunpowder and gelignite

(i) **Gunpowder** consists of the combustibles charcoal and sulphur, mixed with the oxidising agent potassium nitrate (or sodium nitrate), the percentages varying somewhat but being about 15% charcoal, 10% sulphur, and 75% potassium nitrate in Great Britain.

(ii) **Gelignite** consists of about 60% nitroglycerine and nitroglycol, gelatinised with 5% collodion cotton and mixed with about 7% wood meal (a combustible) and 27% potassium or sodium nitrate (an oxidising agent). The remainder consists of calcium carbonate (a stabiliser) and moisture.

3. (a) Why is nitroglycerine never used alone as an explosive in coal mines? (b) Why is ammonium nitrate never used alone?

NITROGLYCERINE AND AMMONIUM NITRATE

(a) **Nitroglycerine** is never used alone because, in its pure state, it is an oily fluid, inconvenient to handle and dangerously susceptible to accidental ignition. Its temperature of detonation is extremely high. If it touches the skin it causes violent headaches. It freezes at 46°F, unless mixed with nitro glycol which lowers the freezing temperature to —8°F. For use in coal mines, it must be mixed with other substances to render it safe to handle and reduce its flame temperature.

(b) **Ammonium nitrate** is never used alone because it is too difficult to detonate by an ordinary detonator. It must therefore be mixed with either nitroglycerine and nitro glycol, or with tri-nitro-toluol (or similar compound) to act as a "**sensitizer.**" It is also very hygroscopic (liable to absorb moisture) and (even when mixed with other ingredients) it must be kept enclosed in a water-proof wrapper. If it becomes wet, it is liable to incomplete detonation.

4. Given that a certain explosive contains (a) nitroglycerine, (b) nitroglycol, (c) nitro-cellulose, (d) nitrate of sodium, (e) chloride of sodium, (f) wheat flour and (g) nitrate of ammonium, state the purpose of each item.

CONSTITUENTS OF AN EXPLOSIVE

(a) **Nitroglycerine** is the primary high explosive in the mixture. It is easily detonated and also acts as a "sensitizer" for the ammonium nitrate.

(b) **Nitroglycol** has properties similar to those of nitroglycerine but a much lower freezing temperature, rendering the explosive safer in cold conditions.

(c) **Nitro -cellulose** (or collodion cotton) is itself explosive and is used to gelatinise the nitro-glycerine, rendering it more water-resistant.

(d) **Nitrate of sodium** is an oxidising agent, to ensure complete combustion and prevent or reduce the formation of carbon monoxide.

(e) **Chloride of sodium** is a cooling agent.

(f) **Wheat flour** is a mere combustible.

(g) **Nitrate of ammonium** fulfils a variety of functions, being an explosive, an oxidising agent, and a cooling agent at one and the same time. It has a less shattering effect than nitro-glycerine; it supplies excess oxygen to the wheat flour; and its temperature of detonation is relatively low.

In general, the explosive in question may be described as a gelatinised nitroglycerine type of explosive.

5. Sketch and describe an ordinary instantaneous detonator, explaining the differences between high-tension and low-tension detonators.

THE LEAD AZIDE DETONATOR

(For the sketches, the student is referred to Figs, 1 and 2 of the Lesson).

The standard electric detonator now used in British coal mines is of No. 6 strength and consists essentially of a copper tube, about ¼ in. diam. and 1 ¼ in. long, containing (a) an explosive charge and (b) an electric fuse assembly.

The explosive charge consists of a top priming charge (0.35 gm.) which is sensitive to the flash from the fusehead, and a bottom detonating charge (0.25 gm.), which is ignited by the priming charge. The priming charge is a mixture of lead azide, lead styphnate and aluminium powder (ASA) and the detonating charge is either P. E.T.N. or tetryl, the former now being preferred.

The electric fuse assembly consists of (a) two tinned iron or tinned copper insulated **leading wires** which pass through a neoprene plug and are soldered to (b) **two strips of brass foil** separated by pressboard. The lower ends of the brass strips are themselves embedded in (c) **a fusehead** of flashing composition which is ignited when a small electric current is passed through it.

In a low-tension detonator, the two brass strips are connected at their lower ends by a fine, wire bridge of nickel chromium alloy which provides a definite metallic circuit for the current.

In a high-tension detonator, there is no wire bridge and the fusehead is of somewhat different composition, including some graphite which forms a semi-conducting medium for the electric current.

Low-tension detonators have an almost constant resistance of about 1 ohm and are more reliable than high-tension detonators. They can also be readily tested by a galvanometer to verify the continuity of the wire bridge and of the whole of the shot-firing circuit. High-tension detonators "have a high and very variable resistance (up to 30,000 ohms) and cannot be tested for continuity so that, whilst they were used at one time for firing single shots, they are entirely unsuitable for simultaneous shot-firing where a number of shots are connected in series. Low-tension detonators are now standard in British collieries.

6. What type of permitted explosive do you consider to be the most suitable for use in (a) hard cross-measure drifts, (b) roof rippings, and (c) coal? Give reasons, (d) State the composition of any one of them, if known.

USE OF VARIOUS TYPES OF EXPLOSIVE

(a) **For hard cross-measure drifts**, a powerful explosive with a high velocity of detonation is needed in order to shatter the rock from the solid and ensure good fragmentation. This calls for a high density, gelatinised nitroglycerine type of explosive, unsheathed Polar Ajax being a typical example.

(b) **For roof rippings**, a less powerful explosive will normally suffice, for the rock has at least two free faces, the depth of burden is more limited, and the strata may range from sandstone on the one hand to soft shales on the other. No single explosive can meet these varying requirements, but there are a variety of gelatinous or powdery explosives from which a selection can be made. Where the ripping is within 60 feet of the face, only a sheathed or an Eq. S. explosive must be used. Unifrax is a typical example (Eq.S.).

(c) **For coal**, and especially where large coal is required, an explosive is **needed that** has a rending or spreading effect. This calls for an explosive of medium or low density within the Eq. S. range, a typical example being Tolumite.

(d) This part of the question must be answered by each student for himself, but the following Table gives the approximate analysis (average figures only) of a number of permitted explosives which students may find helpful.

Approximate Composition of some Permitted Explosives.

Ingredients	Polar Ajax	Unigel Eq.S.	Unifrax Eq.S.	Tolumite Eq.S.	Hydrobel
N-G +Nitro-glycol	26.5	27.3	12.2		39.4
Nitrocellulose	0.75	0.9			2.0
Mono-nitro-toluene	1.8	1.2			
Trinitrotoluene				5.4	
Ammonium Nitrate.	40.5	31.0	49.9	55.1	20.0
Sodium Chloride	24.5	29.3	30.5	35.8	27.1
Oat Husk Meal	3.5	1.4			
Wood Meal				3.7	1.1
Plant Fibre			7.2		
China Clay	2.5	4.3			
Barvtes		4.3			9.7
Others	0.25	0.6	1.1		1.0

Of the foregoing, **Polar Ajax and Unigel** are gelatinous explosives, **Unifrax** is of the N-G powdery type, **Tolumite** is a non N-G powdery explosive and **Hydrobel** is a special water-resisting gelatinous explosive for use in Pulsed Infusion Shotfiring.

It must be realised that new developments in explosives and in shot-firing technique are constantly taking place and students should endeavour to keep in touch with these as they occur.

7. Give a list of the chief causes of accidents causing personal injury and arising out of the use of explosives in mines, apart from accidents causing ignition of gas or coal dust.

CAUSES OF ACCIDENTS FROM EXPLOSIVES

(1) **Not taking proper cover.** This is **the most common cause** of personal injury due to explosives. It is essential that the shot-firer shall himself take adequate cover and see that all workmen in the vicinity of a shot are removed to a safe place. No place in direct line with a shot can be regarded as safe and every person should be protected by at least one right-angled corner. All approaches to the danger zone should be guarded by sentries or otherwise so as to prevent anyone entering inadvertently.

(2) **Failing to warn persons in an adjoining place** into which the shot may explode.

(3) **Carelessness in handling detonators**, causing them to explode, or to be lost in the mine.

(4) **Carelessness whilst charging a hole**, e.g. tamping too forcibly in the neighbourhood of the detonator, or ramming the primer cartridge into a hole of insufficient diameter.

(5) **Firing a shot when persons are at the shothole** due to instructions being misunderstood, or lack of proper sentries.

(6) **Returning to the face too soon** after firing a round of shots, one of which is a "hang-fire" (i.e. a delayed ignition), or before authorised to do so by the shot-firer.

(7) **Tampering with miss-fired shots**, other than in the prescribed manner.

All the foregoing have, at some time or other, been the cause of accident, and they can all be avoided by carrying out the rules laid down in the Explosives Order and by the exercise of just ordinary care.