THE
SHOT-FIRER'S GUIDE:

A Practical Manual for the Prevention of Mining Accidents.

BY

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THE SHOT-FIRER'S GUIDE:

A Practical Manual on Blasting and the Prevention of Blasting Accidents.

BY

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INTRODUCTION.

In the SHOT-FIRER'S GUIDE an attempt is made to place at the service of explosives users in mines and quarries simple, practical explanations concerning the most approved types and methods of handling blasting apparatus and the precautions that are necessary in order to secure safety.

Every stage of a blasting operation is described in detail; instances are given of the varieties of accident which most frequently occur; and the very important question of shot-firing in fiery and dusty mines is considered in the light of the most recent inquiries.

It is hoped that by thus seeking to familiarise mine officials, shot-lighters and others with the risks involved in underground shot-firing, and with the skilful use of modern methods of ignition, something will be done to lessen the annual toll of lives which Nature exacts as the price of failure to comprehend her laws.

In Great Britain alone 106 mine explosions have been caused by shot-firing during the past 10 years. In the same period more than 3,000 persons have been injured and over 500 killed by accidents arising out of the use of explosives.

On the average, one person is injured every day and one dies as the result of his injuries each week throughout the year.

Few of these casualties partake of the nature of unforeseeable occurrences. For the most part they are the result of inexperience or of thoughtlessness, and form a powerful argument in favour of the employment of men who are known to possess sufficient knowledge of the duties upon which they are engaged.

The definition of "sufficient knowledge" must necessarily be provisional, and dependent on the current attainable standard of proficiency in the class of workmen concerned.

At least one qualification upon which stress has not hitherto been laid is likely soon to become an essential condition of appointment to the position of deputy or shot-firer —this is the ability to accurately detect minute percentages of "gas."* If, in addition to this acquirement, a candidate can show that he knows the Official Regulations, and is able to explain their *raison d'être*, he is probably a competent person to fire shots in a mine. If the shot-firer is also a deputy, it is desirable that he should hold an under-manager's certificate, or, at least, be able to answer satisfactorily some such series of questions as that which appears on p. 154 of this book.

At the present time mine officials, miners and quarrymen possess, as a rule, singularly little knowledge of the materials they use, when one considers the enormous development during recent years of educational facilities. Generally, they have only a vague and inarticulate idea of the risks they run during the operations of priming, stemming and firing a charge.

In coal mines, where the normal risks of blasting are liable to be accentuated by special conditions, it is exceptionally important that every individual should be fully cognisant of the probable and possible consequences of his every act.

* See Appendices I. and II.

When regard is had to these extra dangers associated with the use of explosives in mines, namely, those which are to be apprehended from fire damp and coal dust ; when it is seen that some of the greatest mine explosions on record, and no inconsiderable proportion of the lesser disasters of the same kind, have been traced or held to have been caused by the reckless, or at any rate inexperienced, use of explosives; and when to these is added the long tale of minor accidents, which are of almost daily occurrence, the wonder is, not that there are so many official rules to be observed, but that untrained persons should be allowed to fire shots at all. It has been stated in evidence before the Coal Mines Commission now sitting that " 90 per cent., if not the whole, of those who are 'competent shot-firers' (under the Mines Acts) have no theoretical knowledge at all as to explosives."

There is little room for doubt as to the general accuracy of this statement, and it is greatly to be desired that those to whom it refers should rise to their responsibilities and emerge from the ranks of that immense army of semi-competents who do so much to block the path of industrial progress.

This Manual is published at a low price in order that it may be within the reach of every workman.

It is set in Question and Answer form because this arrangement has been found to be especially adapted to the needs of those for whom it has been prepared. It is to some extent a re-set abridgment of the Author's book on "Electric Blasting Apparatus and Explosives," but advantage has been taken of the opportunity to revise the data on explosives in conformance with the classification adopted in the Report of the Committee on Bobbinite.

A considerable amount of new matter has also been added, including references to such recent work bearing on the safety of shot-firing in fiery and dusty mines as Dr. Henry H. Payne's Paper before the Coal Mining Institute of America, Dr. Snell's Presidential Address to the British Medical Association at Sheffield, and the valuable experiments that are being carried out by the Mining Association of Great Britain at Altofts.

The Report of the Departmental Committee on Bobbinite and those of H.M. Inspectors of Explosives have been freely laid under contribution, partly because they form an admirable up-to-date exposition of current expert views on the use of explosives and partly from the Author's desire to bring before a public that does not read Blue Books a knowledge of the valuable inquiries which H.M. Home Office Departments of Mines and of Explosives are constantly placing at the disposal of all who care to seek.

For permission to make use of these Official Publications acknowledgments are due to the Controller of His Majesty's Stationery Office. The Author also records with pleasure his indebtedness to the works of Dr. Von Schwartz and M. Bichel, and to the Nobel Company and other makers of explosives and shot-firing apparatus who have kindly supplied him with particulars relative to their specialities and electros for purposes of illustration.

WM. MAURICE.

Hucknall Torkard, Notts.

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PART I.

EXPLOSIVES.

1.—Explain, by way of introduction to the subject of Explosives, how an Explosion is produced.

All explosives owe their explosive properties to two causes—namely, the result of temperature and pressure. There is an important axiom in every elementary manual on chemistry—namely, that when chemical action takes place heat and light are generally evolved, and this is most forcibly seen when ordinary combustion takes place. Wood and coal and coal-gas burn readily in air, because there are elements present in these substances which have a great affinity for the oxygen of the air. The carbon combines with the oxygen to form a gas called carbon dioxide (CO_2) and the hydrogen combines to form water (H_2O). In both these reactions the energy of combination is so great that an enormous amount of heat is given out, sufficient to raise the burning bodies to a white heat. A piece of iron if exposed to the atmosphere slowly rusts, the oxygen of the air combining with it to form oxide of iron, or rust. In doing this a certain quantity of heat is formed; but the rusting goes on so slowly that the amount of heat is inappreciable to the senses. If we expedite this action by heating the iron and plunging it into oxygen gas, rusting or combination takes place so rapidly that the iron actually catches fire and burns.

In the latter case the heat given out is intense, and is easily recognised, because the combination takes place so rapidly. It is a proved law that when combination takes place between bodies, exactly the same amount of heat is given out if the process takes a few seconds or takes years to accomplish the same result.

The combination of the oxygen and the iron produces a solid substance called oxide of iron. We can, however, cause certain elements to combine, the products being gaseous. For instance, we turn on a jet of coal-gas in a room; the gas escapes and mixes with the air, no combination taking place. If we warm up the mixture of gas and air by applying a light, the gas immediately catches fire and burns. On removing the source of heat—the match, for instance—the gas does not go out, but continues to burn, because the coal-gas in burning, combining with the oxygen of the air, gives out so much heat that each successive portion of gas issuing from the jet is raised to the point of ignition. In this case the gas burns steadily, owing to the gradual mixing of the gas and air.

If, however, the tap be turned on and the gas allowed to mix with the air of a room, even to so small an extent as 10 per cent. (of the coal-gas), and a light be then introduced, a violent explosion will take place, owing to the whole of the combustible mixture combining, not slowly, but almost instantaneously.

As a result, the room may be wrecked and the doors and windows blown out. This increase of pressure is due to the effect of temperature, for it is well known that when substances are heated they expand, gases expanding more than any other form of matter.

Explosion may be, therefore, caused by intensely rapid combustion, and, as a general rule, it may be stated that all explosives owe their explosive force to the generation of pressure, caused by rapid decomposition, or combination of certain elements, the products formed being largely expanded by the heat evolved, the destructive effect being regulated by the time taken in producing the change of state.

All ordinary explosives consist of two parts—the combustible elements and the oxidising body. Carbon and hydrogen, either free or combined in certain compounds, generally form the combustible part, and oxygen, loosely combined with other elements, as in the nitrates and chlorates, is added to burn up the carbon and hydrogen to form carbon dioxide and steam at a high temperature. (W. J. Orsman, F.I.C., in a lecture before the National Association of Colliery Managers, England.)

2.—How would you explain the difference between Combustion and Detonation?

If an explosive is ignited simply by a spark or flame, a small portion of the explosive mixture is kindled in the first instance, and for a period it is called simply progressive combustion; this produces a slight pressure in the neighbouring layers of gases, and of course naturally heats them; and, by the time the progressive combustion reaches these more highly-compressed gases, and at a higher temperature, the rate of combustion is accelerated until at last it ends in a true explosion being formed. But in the case of a detonating explosive, or a detonating source, the initiation of this explosive wave is set up more rapidly, and the series of operations take place in an infinitely shorter time.

3.—How are Explosives classified?

In the valuable Report of the Departmental Committee on Bobbinite (Cd. 3,423, 1907) explosives are divided into five principal groups, which are as under:—

1. Nitro-glycerine explosives:
   - (*a*) Low per cent. nitro-glycerine
   - (*b*) Medium per cent. nitro-glycerine.
   - (*c*) High per cent. nitro-glycerine.
   - (*d*) Gelatines.

2. Ammonium nitrate explosives.
3. Nitro-glycerine and ammonium-nitrate explosives.
4. Non-detonating mechanical mixtures.
5. Gunpowder.

Of these groups 1, 2 and 3 are detonants, or high explosives. (*See* Q. 12, p. 11.)

4.—What are the Chief Characteristics of the First or Nitro-Glycerine Group?

The chief characteristics of this group depend on the presence of nitro-glycerine. This ingredient being a liquid necessitates the employment of some substance which will retain it in the cartridge as a sponge retains water, or else the presence of an ingredient which will gelatinise it so that it ceases to be a liquid.

A prominent characteristic of this group is that they are relatively easy to detonate under normal conditions, since nitro-glycerine is relatively sensitive. Unfortunately it becomes solid at temperatures well above that of the freezing point of water, and when in this state the cartridges are, generally speaking, more sensitive to rough treatment, but less easy to explode with a detonator.

Hence, after a spell of cold weather the number of accidents due to explosions during the charging of a shot-hole or due to striking unexploded cartridges when removing *débris* is largely increased. In the past a considerable number of fatalities have arisen from the employment of improper means for warming the cartridges to restore them to a plastic condition (*see* pp. 111–113).

All explosives of this group are readily inflammable, and generally, when burnt, instead of being detonated, they give off large quantities of highly poisonous gases.

Low per cent. Nitro-Glycerines.

Sub-group (a), Low per cent. Nitro-Glycerines.— This sub-group may be termed the Carbonite group. The nitro-glycerine, which forms about 25 per cent. of the total weight, is generally absorbed by wood-meal, and to this mixture is added a nitrate, or oxygen carrier (generally nitrate of potassium or barium), thus forming, as it were, a mixture of nitro-glycerine with a wood-meal gunpowder. The carbonites were introduced as a compromise between a highly shattering explosive, such as dynamite, and the non-detonating gunpowder, and were intended for use in coal mines where danger was to be apprehended from fire-damp.

The nitro-glycerine having been, so to speak, diluted or tamed down by a very slow and cool gunpowder, these explosives possess a comparatively low speed of detonation and are alleged, therefore, to be more suitable for coal-getting than any other detonating explosive.

They have successfully passed both the Woolwich and Belgian tests (*see* pp. 70 and 71) and are considered on the Continent to be among the safest of all explosives used in gassy mines. The *charge limite* (*see* p. 133) of carbonite at Frameries is over 900 grammes. They have certain disadvantages, in addition to those inherent in the group, the chief of which is that they are bulky and thus entail the use of relatively large charges and a relatively large diameter of bore-hole.

This sub-group is also generally regarded as being more liable even than the other explosives of the nitro-glycerine group to cause noxious fumes, consisting largely of the inflammable gas carbon-monoxide.

Medium per cent. Nitro-Glycerines.

Sub-group (b), Medium per cent. Nitro-Glycerines.—This sub-group consists of explosives which may be termed strong carbonites, in which the percentage of nitro-glycerine is from 35 to 48 of the total weight. Up to the present they have not been much used in this country. On the Continent, however, they have been employed for some little time, and have successfully passed the Belgian tests at Frameries. Grisoutine II. may be taken as a type. It consists of 44 per cent. of nitro-glycerine, 44 per cent. of sodium sulphate, and 12 per cent. of wood-meal. Its *charge limite* at Frameries is 650 grammes.

Occasionally a small percentage of nitro-cotton is added, and explosives with this ingredient present appear on the Permitted List (*see* pp. 9 and 10) under the names of Dragonite and Normanite, but their use is restricted.

High per cent. Nitro-Glycerines.

Sub-group (c), High per cent. Nitro-Glycerines.—This sub-group is represented by dynamite, which consists of 75 per cent. of nitro-glycerine absorbed by 25 per cent. of kieselguhr.

It was practically the first nitro-glycerine explosive used on a large scale and its chief characteristic is its great shattering power, arising from its high velocity of detonation, which is nearly three times as great as that of carbonite. It will not pass either the Woolwich or the Continental tests.

Sub group (d), Gelatines.—In this sub-group the nitro-glycerine is gelatinised by nitro-cotton, and all the explosives in it can be recognised by their somewhat jelly-like appearances. Included in sub-group (*d*) are such explosives as blasting gelatine, Gelignite, &c. The Bobbinite Committee place them in this order to show the process of evolution. Blasting gelatine, the most powerful explosive used commercially, consists of nitro-glycerine and nitro-cotton only. This composition for various reasons required to be tamed down, and hence it was diluted with carbonaceous materials and oxygen-bearing salts, such as wood-meal and nitrate of potassium, and with these additions it is well known as Gelignite. To pass the Woolwich test it required to be further tamed, and for this purpose not less than 10 per cent. of oxalate of ammonium, which contains a large amount of water of crystallisation, was added, and in this form and under the names of Storvite, Arkite, &c., it passed the Woolwich test. It will not, however, pass the Continental test, charges of 50 grammes almost invariably causing ignitions.

From a blasting point of view the chief feature in the Gelatines is their great local shattering effect, though, as we shall subsequently show, this can be successfully modified by skilful use, and also the fact that they can be used in wet shot holes without great risk of a miss-fire.

To sum up the characteristics of the nitro-glycerine group, the advantages may be said generally to be :—

1. Ready detonation under normal conditions.
2. Plasticity, which enables them to be squeezed into a bore-hole, completely filling it up.
3. In the case of the gelatines, can be used in wet holes.

The disadvantages being :—

1. Liability to become frozen (non-plastic), and then in- increase of sensitiveness to rough usage and decrease of sensitiveness to explosion by detonator.
2. Inflammability.
3. Generation of noxious gases when ignited.

5.—What are the Chief Characteristics of the Second or Ammonium-Nitrate Group?

Ammonium-Nitrate Group.

The chief characteristics of this group depend on the nitrate of ammonium. This salt is very insensitive in the pure state: it can, however, be exploded with great difficulty; it is also hygroscopic and therefore explosives of this group have to be enclosed in waterproof wrappers.

These explosives generally consist of from 80 per cent. to 90 per cent. of nitrate of ammonium, to which is added a combustible which is sometimes a nitro-compound, such as tri-nitro-toluol, and sometimes a hydro-carbon, such as naphthalene, or even carbon in the form of charcoal. Their velocity of detonation is considerably less than that of dynamite or the gelatine explosives, but above that of the carbonites, and hence, so far as shattering effect is concerned, they occupy an intermediate position.

A large number have been successfully tested at Woolwich, but relatively few appear able to pass the Continental test.

In this group is to be found "Favier poudre," which is said to have originated the explosion at the Courrières mine; it is very similar to Ammonite, which has passed the Woolwich but which fails to pass the Belgian test.

The chief advantages of this group may be said to be :—

1. Their comparative safety in handling.

2. The ease with which they can be rendered non-explosive. Whilst their disadvantages are :—

1. The difficulty of keeping the cartridges waterproof.
2. Bulkiness.
3. The liability of failure to explode.

6.—Describe the Third or Ammonium-Nitrate and Nitro-Glycerine Group.

Ammonium-Nitrate and Nitro-Glycerine Group.

The explosives in this group have been introduced with the view of getting over the difficulty in detonating ammonium-nitrate explosives. Generally speaking, about 8 per cent. of nitro-glycerine absorbed in 8 per cent. of wood-meal is mixed with about 84 per cent. of nitrate of ammonium. These explosives will detonate fairly freely even when the nitro-glycerine is frozen, but they have to be made up in waterproof cartridges. Great difficulty has been experienced in providing a suitable method of waterproofing the cartridges.

These explosives have only come into use comparatively recently in this country, but they have been manufactured in Germany for some years.

Those which are on the Permitted List would probably fail to pass the Continental test, but as somewhat similar explosives have *charge limites* of 500 grammes assigned to them in Germany, it is probable that, with slight modifications, the British-made explosive could be manufactured to pass the Continental test.

7.—What are the Characteristics of the Fourth Group—Non-detonating Mechanical Mixtures?

Non detonants.

The only explosives of this class are Amasite, Aphosite, Bobbinite, and Virite.

The first is a new explosive; the second is used in two or three collieries and the last is not now manufactured. It remains, therefore, only to deal very shortly with Bobbinite. This explosive in its action resembles gunpowder, and is consequently popular with miners who have been accustomed to blast with gunpowder. Like that explosive, it requires to be efficiently tamped to obtain good results. Bobbinite consists of a high-grade gunpowder containing but little sulphur, mixed with starch and paraffin wax and pressed into a pellet which is coated with paraffin wax.

The method of its manufacture is very similar to that employed for the production of gunpowder. It will not pass the Continental tests, as when unstemmed it does not explode properly.

8.—Describe the Gunpowder Class of Explosives?

Gunpowder. The characteristic of gunpowder and the explosives of Group 4 is their low velocity of explosion, which renders them very suitable for work where a slow heaving action is required.

A further advantage in use for coal-getting accrues from the fact that an overcharged hole is not penalised by the production of slack to the same extent as with a detonant; this, however, turns to a disadvantage when there is a risk of igniting fire-damp, as an overcharged hole is a distinct source of danger.

Gunpowder will not pass either the Continental or Woolwich tests.

9.—Give the List (July 3, 1909) of Permitted Explosives classified according to their Ingredients.

Group I.—Nitro-Glycerines.

Sub-group (a), Carbonites:

Britonite.	Kynite.	Phœnix Powder.
Cambrite.	Kynite Condensed.	Pit-ite.
Carbonite.	Nobel Carbonite.	Tutol.
Clydite.	Oaklite No. 1.	Victorite.
Kolax.	Oaklite No. 2.	

Sub-group (b), Strong Carbonites:

Dragonite.	Extra-carbonite.	Normanite.

Sub-group (c), Gelatines:

Albionite.	Cornish Powder.	Rippite.
Arkite.	Dominite.	Russelite.
Celtite.	Fracturite.	Samsonite
Cliffite.	Haylite No. 1.	Stow-ite.

Group II.—Ammonium-Nitrates.

Ammonal.	Odite.	St. Helen's Powder.
Ammonal B.	Permonite.	Roburite No. 3.
Ammonite.	Permonite II.	Thunderite.
Amvis.	Ripping Ammonal.	Titanite.
Bellite No. 1.	Bellite No. 3.	Titanite No. 1.
Colliery Steelite.	Curtisite.	Westfalite No. 1.
Good Luck.	Dahmenite A.	Westfalite No. 2.
Minite.	Electronite.	Withnell Powder.
Negro Powder.	Faversham Powder.	

GROUP III.—AMMONIUM-NITRATE AND NITRO-GLYCERINE.

Abbcite. Monobel Powder. Rexite.
Excellite. Permitite. Nobel Ammonia Powder

GROUP IV.—NON-DETONATING MECHANICAL MIXTURES.

Aphosite. Bobbinite. Virite.
Amasite.

10.—Give a Table showing the Consumption of Explosives in British Mines and Quarries during the Year 1908.

Table I.

Name of Explosive.	Quantity used.	Percentage of total.
	Lb.	
Permitted explosives	8,297,738	26·9
Gunpowder	18,736,168	60·9
Gelignite	2,737,468	8·9
Blasting Gelatine		
Dynamite	668,401	2·2
Gelatine Dynamite		
Cheddite	249,996	0·8
Various	103,952	0·3
Total............	30,793,723	100·0

11.—How would you identify a Permitted Explosive?

Since the 1st of March, 1907, the use of a permitted explosive is conditional on each cartridge bearing a mark showing

FIG. 1.—COMPULSORY MARK ON A PERMITTED EXPLOSIVE.

it to be a permitted explosive. The marking is the outline of a crown with the letter P in the centre, as shown in Fig. 1.

Chapter I.—PART II.

DETONATORS AND FUSES.

12.—What is the difference between a Detonant and a Non-detonant?

The difference between a *detonant* and a *non-detonant* will be understood when it is recognised that explosives vary very much in their rapidity of combustion—that is, in the time which it takes for a given weight to explode.

In some materials the accumulated chemical energy is released slowly, producing a change which is called *combustion.*

In other materials the transformation of energy takes place with greater rapidity and is then called *explosion.*

In yet other materials the change occurs with such extraordinary rapidity that the conversion of the solid matter into gases and vapours is practically instantaneous. This phenomenon is called *detonation.* The force produced by an explosive depends on the rapidity with which it is converted into gases, and, since there is no sharp dividing-line between one explosive and another, the different classes form series passing from a stage bordering on simple combustion to a stage of true detonation.

In practice, however, blasting agents can be divided into (*a*) those which are exploded by simple ignition and (*b*) those which require to be exploded by detonation. The former are called *non-detonants* and the latter *detonants.*

13.—What is Safety Fuse, and how is it applied to the Firing of Non-detonants?

Non-detonants, of which class gunpowder and Bobbinite are the principal representatives, ignite on the simple application of sufficient heat, usually through the medium of a *fuse,* consisting of a cord, taped or otherwise covered, containing a core of fine gunpowder.

Safety fuse, the invention of William Bickford, of Tuckingmill, Cornwall, was designed by the inventor to obviate the various dangers inseparable from the use of "Germans" and other still used but happily obsolescent methods of conveying fire to a blasting charge.

Numerous and important improvements have been effected by the inventor's successors since 1831, the year of the original patent, which have resulted in the introduction of different qualities of fuse, adapted to all the various requirements of modern blasting.

The following Table illustrates some of the principal descriptions of safety fuse now used.

Table II.—*Bickford's Safety Fuse.*

Maker's Number.	Description.	Purpose.
1	Small fuse	For immediate use in dry ground
4	Red fuse	For use in damp and close places
8	Tape sump fuse	For use in wet ground
9	Double tape sump fuse	For use in very wet ground
13	Gutta-percha fuse ..	For use in water
15	Double gutta-percha fuse	For use in 300 ft. water
23	White tape fuse	For use in wet and close places, and for exportation into warm climates
24	White double tape fuse	For very wet and close places, and for use in hot climates
25	Patent colliery fuse..	To convey fire without emitting sparks or fire laterally during combustion

To fire a charge by means of fuse, a suitable length is cut off obliquely and inserted through a hole in the centre of the primer cartridge, as shown in Fig. 2. When the required weight of charge has been placed in the bore-hole the primer is added, the whole carefully tamped, and a light applied to the free extremity of the fuse.

The combustible core thus ignited burns along the inside of the cord and ultimately sends out a spurt of flame from the end which is shown reversed in the cartridge, Fig. 2. (The object of reversing the end of the fuse is to form a wedge, as it were, and so prevent its accidental withdrawal during the operation of stemming.)

As a guide to safety, it may be stated that ordinary Bickford fuse burns at the approximate speed of 1 ft. in 30 seconds, but some margin of time should be allowed for variations from atmospheric or other causes.

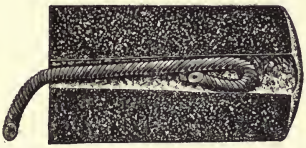


FIG. 2.

14.—How are Detonants Fired by Fuse Ignition?

The *detonants* cannot ordinarily be exploded by simple ignition, but must receive an extremely violent shock such as can only be produced by another explosion of the most rapid kind, namely, *detonation.*

This initial detonation is obtained by the use of certain extremely explosive salts called *Fulminates*, which are derived from fulminic acid or nitro-acetonitrite, the chemical formula for which is $CH_2(NO_2)CN$. The best known and the one which is used for blasting purposes is mercuric fulminate. It is obtained by the action of alcohol and nitric acid on mercury nitrate and has the chemical formula $Hg_2C_2N_2O_2$.

This compound is extraordinarily unstable. It explodes when heated to about 360°F., when scratched by a pin, and when brought into contact with an electric spark, or with concentrated sulphuric and nitric acids. When thoroughly wet it is inexplosive.

In the practical application a small quantity of fulminate (mixed with chlorate of potash) is put into a solid-drawn copper tube, closed at one end, in such a manner as to form in effect a solid piece of fulminate which would appear in section as shown in Fig. 3. This is called a detonator.

Fig. 3.

The standard composition of charge for Nobel detonators is shown in Table III.

Table III.—*Standard Mixture for Detonators.*

	For safety fuse blasting.	For electric blasting.
Fulminate of mercury.	80 per cent.	95 per cent.
Chlorate of potash ..	20 ,,	5 ,,

Sometimes aluminium powder is mixed with or pressed on the top of the fulminate, while the new Tetryl detonator, as used by The Roburite Co., is made of Tetra-nitro methyl aniline.

An illustration showing a group of detonators (actual size) appears in Fig. 4.

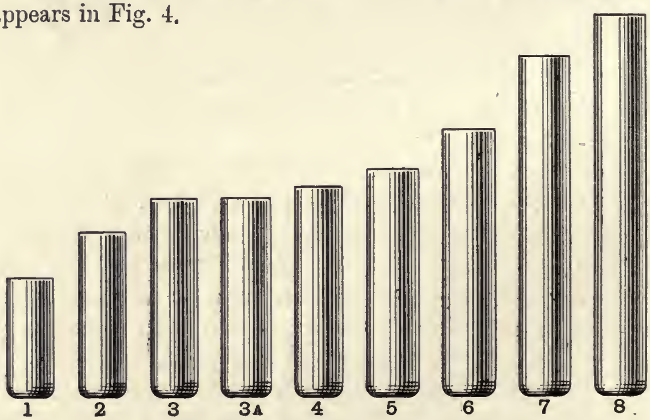


Fig. 4.—Detonators. (Actual Size.)

To prepare a fuse for the explosion of a detonant a piece is cut obliquely from a coil, either with a sharp knife or by means of the special tool as shown in Fig. 5.

The safety fuse is then inserted in a detonator and fixed by means of the nippers, as shown in Fig. 6.

For use in water, or in a wet bore-hole, it is necessary to make the junction of the fuse and detonator watertight, either by means of grease or by the use of adhesive insulating tape of the kind used for electrical joint making.

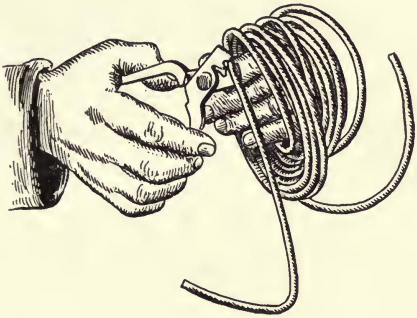


FIG. 5.

The manner of preparing the primer cartridge, as recommended by Nobels, Ltd., is as follows:—Take the cartridge, open at one end, and by means of a small pointed stick, or the handle of the nippers, make a small hole in it, and then insert the detonator in the hole so that about one-third of the copper

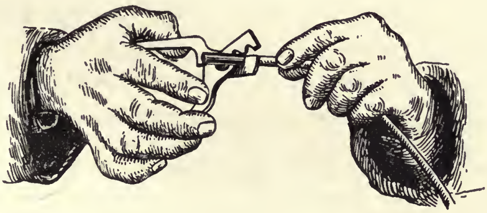


FIG. 6.

tube is left exposed outside of the explosive. The safety fuse, just above the detonator, should be securely tied in position in the cartridge, as shown in Fig. 7. If the detonator is pushed too far into the cartridge, the safety fuse may set fire to the cartridge before the detonator can act. This circumstance and the use of defective, inferior, or damp detonators are fruitful causes of unpleasant fumes and frequently lead to only partial detonation of the explosive.

The primer so prepared is stemmed and fired as explained in the chapter on PRACTICAL APPLICATIONS, p. 80.

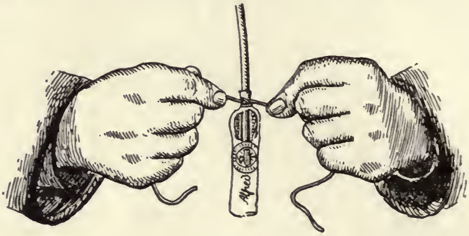


FIG. 7.

15.—How can Safety Fuse be used in Fiery Mines?

In all coal mines in which inflammable gas has been found within the previous three months in such quantity as to be indicative of danger, only "permitted explosives" may be used, and if required to be exploded by safety fuse, the only permissible means of ignition (other than electrical) is by a "permitted igniter fuse" of the kind manufactured by the firm of Bickford, Smith & Co. Bickford's igniter fuse consists of a tube of tinned iron or steel, closed at one end, and containing a mixture of

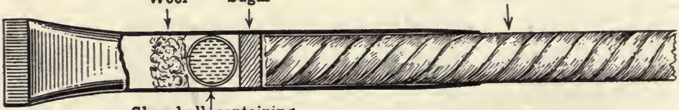


FIG. 8.—SECTION THROUGH BICKFORD'S IGNITER FUSE.

chlorate of potassium and sugar pressed into a pellet, in close contact with a hermetically sealed glass capsule containing concentrated sulphuric acid. A section through such an igniter fuse is shown in Fig. 8, and a perspective view of the same in Fig. 9.

The ignition of the fuse is effected by breaking the glass capsule and so allowing the sulphuric acid to come into contact with the chlorate of potash.

A very powerful oxidising agent known as chlorine peroxide (ClO_2) is thus produced, and when generated in the presence

FIG. 9.—PERSPECTIVE VIEW BICKFORD'S IGNITER FUSE.

of such a substance as sugar the oxidation is so vigorous that the sugar takes fire. An igniter fuse of this description may be used as a substitute for open flame ignition anywhere except in places to which the Explosives in Coal Mines Order applies.

Only a *permitted* igniter fuse may be used in those places where the Coal Mines Order applies. The essential difference between an igniter fuse and a permitted igniter fuse is in the requirement that the latter class must be of special quality and must be supplied permanently attached to its igniter.

Specifically, the fuse (No. 25, Table II., p. 12) must consist of a core of gunpowder in weight not exceeding 6 grammes per metre (0·21 oz. (avoir.) per 1·09 yards), traversed by two threads and enclosed by :—

(1) a layer of jute yarn ;
(2) a layer of jute yarn laid in the contrary direction ;
(3) a layer of tape ;
(4) a layer of tape laid in the contrary direction ;
(5) a layer of jute yarn secured by a suitable varnish ;

FIG. 10.

the three outer layers being specially treated with a fire-proofing composition.

This fuse must be fitted into the open end of the igniter, securely attached thereto, and the joint cemented by a tape bearing the "Crown" and the letter "P." The permitted igniter fuse presents the appearance seen in Fig. 10.

It is further provided that the permitted igniter fuse shall be fired only with the implement supplied by the manufacturer and according to the instructions enclosed in each package.

The implement referred to, namely, Bickford's patent nippers, is shown in Figs. 11 and 12. They are so constructed that,

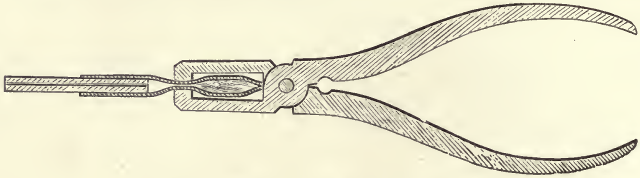


FIG. 11.—BICKFORD'S PATENT NIPPERS.

when the lighter has been inserted longitudinally, the nippers will close *exactly* on the right spot to be pressed for firing. The lighter could be fired with any nippers, but the inexperienced operator might not always squeeze at the exact point with the accuracy ensured by the use of Bickford's patent nippers, which serve also as a gauge and cannot fail.

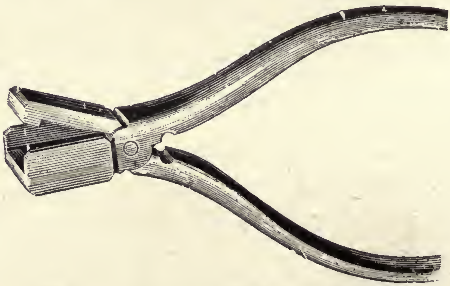


FIG. 12.—BICKFORD'S PATENT NIPPERS.

The chamber of the nippers entirely surrounds and encloses that portion of the lighter in which the ignition takes place, thus effectually preventing the possibility of a spark reaching the outer atmosphere. The slots in the handles are for use with ordinary igniters and serve the purpose of closing the open end of the lighter tube around the fuse before firing.

16.—By virtue of what electrical property can Fuses be ignited?

For the purpose of securing greater safety to workers in mines and in the conduct of blasting operations generally electrical methods of exploding charges have been developed and are very extensively used. In these methods advantage is taken of the fact that a wire of a given diameter will only carry safely a definite quantity of electric current. If this quantity is exceeded the wire becomes hot, by virtue of the property known as *resistance*, and may even be melted if sufficient current be supplied to it. If, therefore, two pieces of wire are taken which will safely carry a given current, and the extremities at one end be joined by a short length of wire very much thinner and which is consequently unable to carry the same current, this short length will become incandescent and set fire to any ignitible mixture with which it may be in contact when the free ends of the wires are connected with a suitable source of electrical energy.

17.—What is an Electric Fuse?

An electric fuse consists essentially of a pair of conducting wires which are joined at one end by a thinner wire or a chemical composition which is capable of becoming incan-

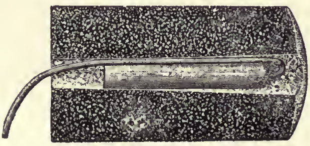


FIG. 13.

descent on the passage through it of a suitable electric current, the said wire or composition being either inflammable itself or in contact with an inflammable mixture.

This inflammable mixture, together with the part called the *fuse-head*, which is to produce ignition, is generally contained in a paper tube about $1\frac{1}{4}$ in. long and $\frac{1}{4}$ in. in diameter which in contact with a cartridge appears as shown in Fig. 13.

18.—There are two systems of Electric Fuse ignition. How are they defined?

There are two distinct classes of electric fuses, and many varieties of each class.

The classes are commonly known as HIGH-TENSION and LOW-TENSION fuses respectively, and are perhaps best defined by reference to the igniting medium, which connects the wire terminals within the fuse tube or casing.

A HIGH-TENSION fuse is one having its terminal wires bridged by a combustible and conductive composition of relatively high electrical resistance, as indicated diagrammatically in Fig. 14.

A LOW-TENSION fuse is one having its terminals metallically connected, as in Fig. 15, the connection being surrounded by and in contact with a combustible mixture.

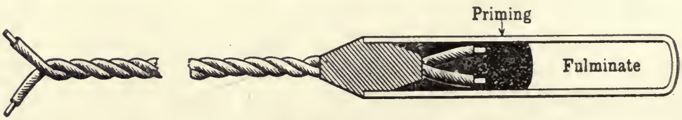


FIG. 14.—HIGH-TENSION FUSE.

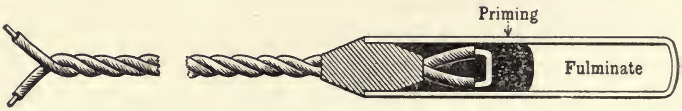


FIG. 15.—LOW-TENSION FUSE.

19.—How does Ignition occur in (a) High-tension Fuse, (b) Low-tension Fuse?

In the case of *high-tension fuses*, ignition occurs in the following manner: Electrical energy at the fuse terminals (technically, the *fusehead*) is, owing to the insufficient conductivity of the bridging composition, converted into heat energy. The heat cannot dissipate with sufficient rapidity, therefore the temperature rises to the point of ignition of the bridge (which may also be the *priming*); the latter then bursts into flame and initiates the required explosion.

With *low-tension fuses* the wire bridge is similarly heated, and so ignites the priming with which it is in contact.

20.—What is an Electric Detonator?

An *electric detonator* consists of the combination of an electric fuse (which may be either HIGH or LOW-TENSION) with a detonator as above described, and presents the general appearance of Fig. 16.

FIG. 16.—ELECTRIC DETONATOR FUSE.

(Figs. 14 and 15, though only intended to show diagrammatically the difference between High-Tension and Low-Tension *fuses*, may also be taken as sectional diagrams of electric *detonators*.)

21.—Describe some of the Electric Fuses and E.D. (Electric Detonator) Fuses generally used in British mines.

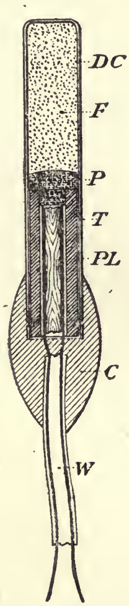


FIG. 17.
HIGH-TENSION DETONATOR FUSE.

A well-known make of high-tension E.D. fuse is shown sectionally in Fig. 17.

To prepare this type of fuse the connecting wires W, consisting of two No. 24 S.W.G. tinned copper wires, separately insulated and then braided together, are bared for a length of about 1 in., the bared wires being then laid in grooves at each side of a small cylindrical wooden plug, PL. A paper strip is rolled around this plug to form a cylinder, T, rather longer than its support, and of an outside diameter approximating to that of the detonator tube. A charge of priming, P, is put in contact with the wire ends, and held in place by a thin membrane or other suitable means. The completed fuse is then placed in a detonator containing the required weight of fulminate F, the outer tube is indented to prevent withdrawal of the fuse, and finally the end is sealed with waterproof cement as shown at C.

In the special low-tension detonator made by the Cotton Powder Co. (Ltd.) two No. 22 S.W.G. tinned copper wires are threaded through a wooden plug, as shown in Fig. 18, which has been drilled to gauge and soaked in varnish. The ends project slightly, as shown in the illustration, and are joined by a platino-iridium bridge two mils (0·002 in.) diameter. This bridge is enclosed in nitrated cotton, no other priming being used.

The fuse is put into the detonator until the priming just touches the fulminate, and is then fixed in position with a suitable waterproof cement.

The Lancashire Explosives Co. (Ltd.) produce a compound detonator fuse in the design of which great care is taken to preclude the possibility of miss-fires, which are a constant source of danger and expense. The fusehead in this construction is of wood, through which two separate passages Z are bored (Fig. 19), and through which the wires are drawn in such a

FIG. 18.—No. 7 L.T. DETONATOR.

manner that they cannot come into contact. The ends of the wires terminating in the internal powder-chamber C are passed through a perforated disc of non-conducting material, G, and securely riveted, forming two copper heads, as shown at F,

The fusehead is formed as shown in elevation (Fig. 20), so that when inserted into the detonator the distance between the priming composition and the fulminate is constant, being precisely four millimetres. This tends to ensure the projection of the flash from the priming composition direct on to the fulminate B. The priming E in these fuseheads is moulded under pressure into the shape of a nipple, the apex of which, offering the least resistance, ensures a central fire.

A coat of varnish, D, protects the priming composition, and the insulated wires Y are twisted (as shown in Figs. 19 and 20) n order to prevent any movement in the fusehead. A detonator, A, is finally added and swaged into the recess H of the fusehead so that it cannot be withdrawn.

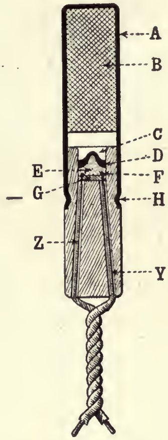


Fig. 19.—Section of Fusehead and Detonator. (Full size.)

Fig. 20.—Elevation of Fusehead. (Full size.)

In the Tirmann patent fuse of Messrs. Bickford, Smith & Co. there are some radical departures from the general methods of fuse construction. The casing consists of a lead alloy capsule

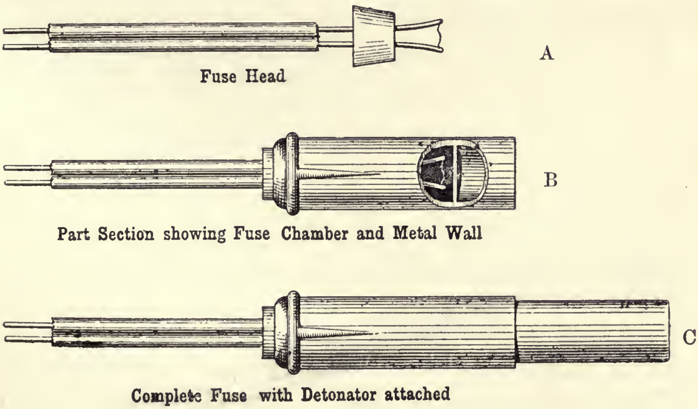


Fig. 21.

in two divisions, or, in other words, of a tube, the way through which is blocked in the middle by a metallic wall, homogeneous with the tube itself.

One end of the tube (Fig. 21B) contains a charge of priming composition in which are embedded the ends of the conductors bridged by a very thin platinum wire, as shown in Fig. 21A.

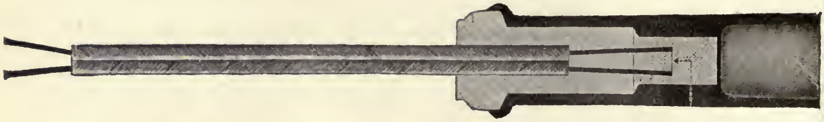


Fig. 22.—Section through Tirmann Fuse.

The fuse-head is made fast in the casing by sulphur cement. These fuses are machine-made and are tested three times in course of manufacture. Great care is taken to make the fuse bridges of perfectly equal electrical resistance, so as to facilitate their application to simultaneous firing in great numbers. They are sometimes made with iron and sometimes with copper

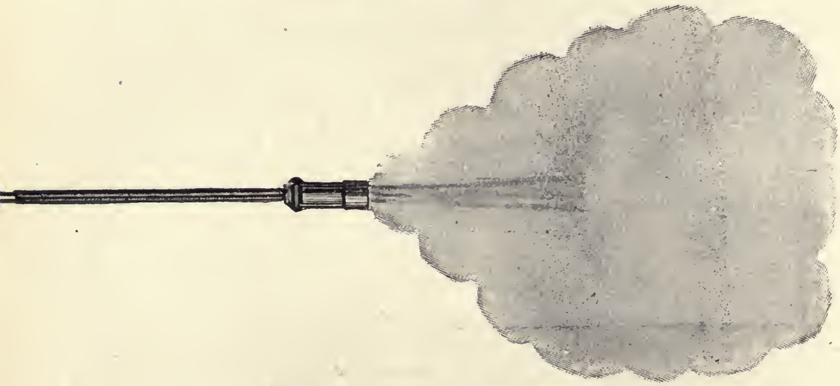


Fig. 23.—Explosion of a Tirmann Fuse.

conductors, either pattern being insulated, of course, suitably to the nature of the work for which it is intended. With iron wires 1 metre (3 ft. $3\frac{1}{3}$ in. approx.) long, the total resistance of a Tirmann fuse is 1 ohm. Using a copper conductor of the same length the resistance is reduced by half. The free end is slightly coned inside (*see* Fig. 22) to hold a detonator tightly without further manipulation. The fuse being put over the detonator instead of within it, as in other patterns, eliminates the risk of exploding the cap by friction. When the platinum wire bridge in this patent fuse becomes incandescent through the passage of an electric current the explosion of the priming so caused, bursts the metal wall which divides the cap into two parts and projects a fire stream through the tube with the action of a shot from a pistol. Fig. 23 illustrates the manner of firing.

An interesting development of the paste form of priming is that employed by the Roburite Explosives Co. (Ltd.). This firm, instead of using a granulated priming, dips the fuse-head (which may be either high or low tension) into a conductive and inflammable composition which adheres and dries on the terminal wires like the tip of a lucifer match. By the adop-

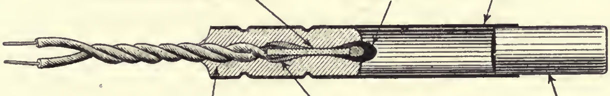


Fig. 24.

tion of this method of construction the spacing of the broken circuit is automatically adjusted by the thickness of the cardboard on to which the metal foil is pasted. Fig. 24 shows this type of fuse in section.

22.—What are Fuse or Detonator Wires?

Fuse Wires. The conducting wires or leads which serve the purpose of completing electrical communication between the firing cable and the fuse-head are sometimes made of tinned iron, but more frequently of copper or brass wire. The size is usually No. 22 I.W.G. (Imperial wire gauge), and the length varies from 8 in. to 45 ft., according to requirements.

The most commonly used lengths for mining purposes range from 36 in., increasing by additions of 6 in. to 5 ft.

Fuse wires should always be a few inches longer than the bore-hole in which they are to be used, otherwise it may be necessary to make joints, and this introduces risk of miss-fires (*see* p. 96).

On the other hand, the use of 48 in. fuse wires instead of 42 in.—that is to say, of wires 6 in. longer than is necessary—would mean, to a colliery company using say 5,000 shots per month, an annual waste of about £18, taking the cost of an extra 6 in. of wire at 6s. per 1,000 fuses.

23.—Is there any choice between High-tension and Low-tension systems of ignition ?

Fuse wires are covered with insulating material to prevent leakage of current from one wire to the other, or from either wire to earth (*see* Part III., p. 77). When intended for use in dry ground, a simple wrapping, consisting of two layers of cotton yarn saturated with an insulating compound, is amply sufficient. For blasting in damp ground or under water india-rubber or gutta-percha covered wires are necessary.

Selection of Fuses.

At the present time custom is, perhaps, fairly equally divided between the use of high and low-tension fuses.

In Great Britain, and generally where extreme climatic changes are not to be looked for, high-tension fuses give most satisfactory results. For group firing "in parallel" they are to be preferred. Low-tension fuses are better for firing "in series" (*see* p. 107), because it is easier to obtain a more exactly uniform electrical resistance in fuses of this type. They are in almost universal use throughout Canada and the United States, and this system is to be recommended wherever long storage or long transport is necessary, and specially for use in tropical countries.

Low-tension fuses remain in good condition for an indefinite period, if stored in a dry place, and their efficiency can be verified at any time by testing with a galvanometer.

This is a great advantage, and one not generally applicable to high-tension fuses. (For Methods of Testing, *see* p. 71.)

24.—What are Delayed-action Fuses, and for what Purpose are they used?

Delayed Action Fuses.

In cross measure headings, shaft sinkings and similar work, great economy of time and of explosives is gained by simultaneously igniting a number of shots the explosions of which occur in successive stages. Many methods of attaining various combinations of instantaneous ignition and delayed action have been devised, and some are touched upon in subsequent chapters.

The simplest and yet most practical methods appear to be those in which the Bickford fuse, graduated in length according to the desired rotation of firing, is used in conjunction with electrical igniters. Messrs. Bickford, Smith supply for this purpose a Tirmann time fuse constructed substantially as above described (p. 24, Fig. 22).

It also is made from a strong metal capsule divided into two parts, but the partition (Fig. 25) which divides them is much stronger. In the middle of this wall

Fig. 25.

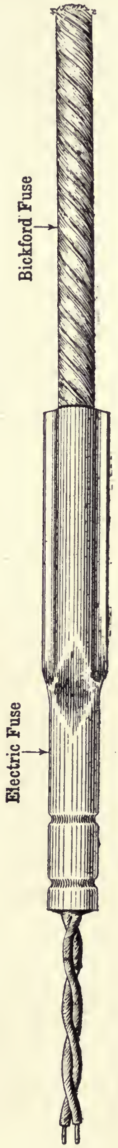


Fig. 26.—Venus (L.T.) with Fuses.

is a very fine hole which connects the priming with the powder core of a Bickford fuse attached to the other end of the fuse. On firing an electric fuse of this type the wall of the metal capsule bursts, and allows free development of gas from the Bickford fuse. Bickford gutta-percha fuse burns at the rate of one centimetre (0·4 in. approx.) per second. From this data the time interval between successive shots can be adjusted as desired.

Mr. Bigg-Wither, of the Roburite Co., has designed an igniter of similar character, which is illustrated in Fig. 26. In this pattern "Venus" low-tension fuses are made up in extra long brass tubes, into which are fitted varying lengths of Bickford fuse to make up delay-action fuses. For wet work each fuse is taped over the space between the arrows (*see* Fig. 26) with adhesive waterproof tape of the kind used for joint-making by electricians.

25.—Describe some Safety Methods of Packing and Carrying Detonators.

Many accidents of a more or less serious nature having occurred owing to want of system or other defect in the method of conveying electric detonator fuses from one place to another, attention has been directed towards the provision of safe arrangements for packing and carrying.

The Lancashire Explosives Co. have registered a system of packing electric detonators which is both simple and practical. The detonators are packed in tens, each one separate from its neighbour, in a cardboard box, details of which are indicated in Fig. 27.

The interior of the box is partitioned as shown in the sectional view. When the ten detonator fuses are inserted, a continuation of the external paper covering, which has been previously slotted and punched to admit the connecting wires, is fitted over them and gummed on to the side of the box. The cover is suitably labelled for registration by the storekeeper, and the complete package when ready for delivery appears as shown in the sketch (Fig. 28).

With detonators packed in this style no further precaution, beyond the provision of a suitable locked case to comply with Rules (*see* p. 174), would appear to be necessary. Ordinarily detonators are carried (in mines) in small tin canisters, the covers of which are firmly secured by means of

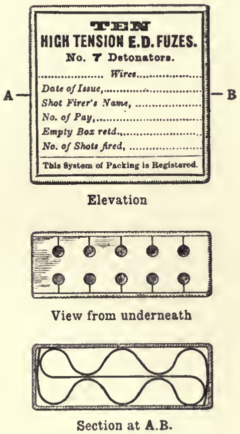


Fig. 27.

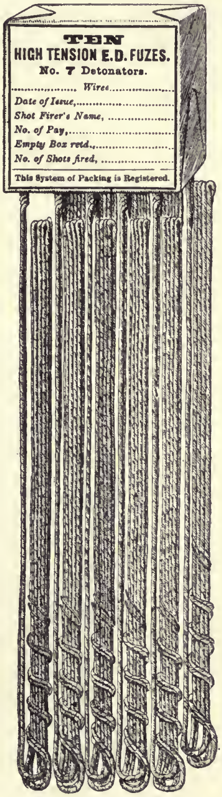


Fig. 28.

a padlock. Such a canister may hold from 5 to 10 detonators having wires of say 36 in. in length. The wires are frequently doubled and intertwined so as to fit into the limited space available. Consequently, when one is required, the entire contents of the case must be withdrawn in order to separate it

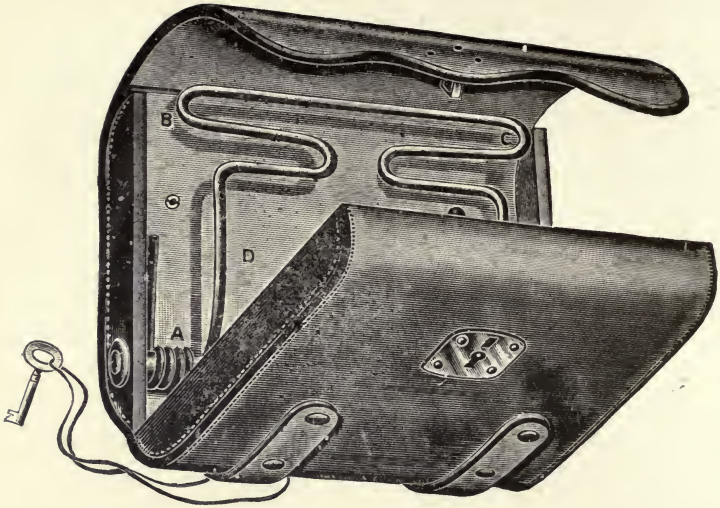
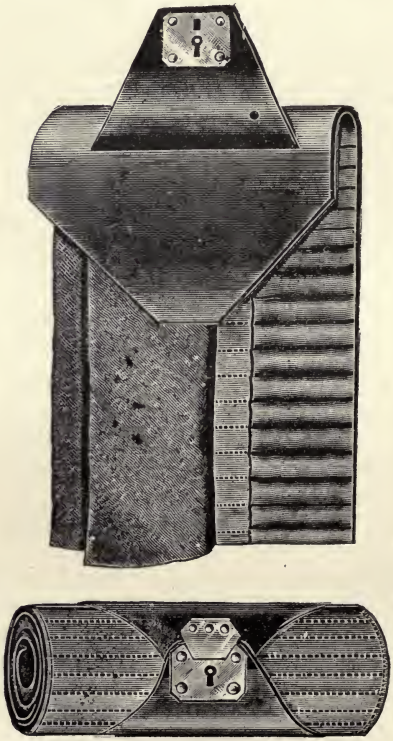


FIG. 29.—THE XL DETONATOR CASE.



FIGS. 30 and 31.—LEATHER DETONATOR CASE, BY THEEDAM, UNFOLDED AND FOLDED RESPECTIVELY.

from the others, and the obviously serious risk of dropping a detonator unawares is thus incurred.

The XL detonator case (Fig. 29) is designed for the carriage of detonators in such a manner that they cannot be accidentally dropped and can yet be easily removed for use.

In the inside of this case, which is made of strong leather, there is fitted a spring wire made in the shape of a double loop, much wider from B to C than it is lower down at D.

The wires attached to the detonator should be wound round the hand and then threaded on the wire from B to C, and dropped down on to the wire D. It will at once be seen that a detonator cannot be removed without manipulating it in the reverse way. The case is made $5\frac{3}{4}$ in. by 5 in. by 2 in.; it is fitted with a spring lock and loops at the back for carrying it on a strap or belt.

Another type of leather detonator case, made by Messrs. Theedam, of Dudley, is constructed in the manner indicated in Figs. 30 and 31, the former of which shows the wallet unfolded for the reception of caps, and the latter folded, to carry in the pocket.

CHAPTER II.

PART I.

EXPLODERS.

26.—What Electrical Appliances and Methods are available for the purpose of Exploding Fuses?

In the early days of the electrical industry almost every machine or device capable of producing an electric current was tried for the purpose of exploding mines or blasting rock.

Frictional machines, induction coils, all kinds of primary and secondary cells and magneto-induction machines have at one time or another done practical service. Modern practice, however, confines itself to the use of (1) Magneto and dynamo exploders, (2) "Dry" or accumulator cells, and (3) Current from power mains. Safety methods of employing the latter source of energy are described in the author's *Electric Blasting*

Apparatus and Explosives, although the application of it in mines is not encouraged, on account of the ever-present possibility of causing premature explosion by leakage current.

27.—How many Types of Current Induction Exploder are there?

Current Induction Exploders.

Current induction exploders may be divided into three types:

(*a*) In which current is induced in coils of wire surrounding the poles of a permanent magnet by suddenly detaching therefrom a soft iron armature.

(*b*) In which a coil-wound armature is rotated between the poles of a permanent magnet.

(*c*) In which a coil-wound armature is rotated between the poles of an electromagnet as in an ordinary dynamo.

Type (*a*), although examples are still used abroad, may be dismissed as lying outside modern practice.

Types (*b*) and (*c*) include all mechanically operated exploders now in general use.

28.—Describe the Construction and Method of Operating Magneto Exploders.

Magneto Exploders.—Type (*b*) embraces the class of magneto exploders, examples of which are to be found in probably every British colliery where electric shot-firing is practised.

A magneto exploder consists essentially of an armature revolving between the poles of a set of permanent magnets. The main difference between a dynamo and a magneto exploder lies in the fact that the former has electromagnets, *i.e.*, soft iron or mild steel wound with insulated wire, through which an electric current passes and magnetises the iron; whilst the latter has hardened steel permanent magnets, without field coils.

Fig. 32 illustrates the type of magneto exploder which has been in general use for many years. It is built up of a series of horseshoe magnets joined together by soft-iron polar extensions, in the magnetic field of which a shuttle-wound armature is rotated. A high armature speed is attained by suitably arranged toothed wheels. Current is produced by rapidly revolving the handle attached to the main driving wheel and is transmitted to the internal or firing circuit by pressing a button. The latter is

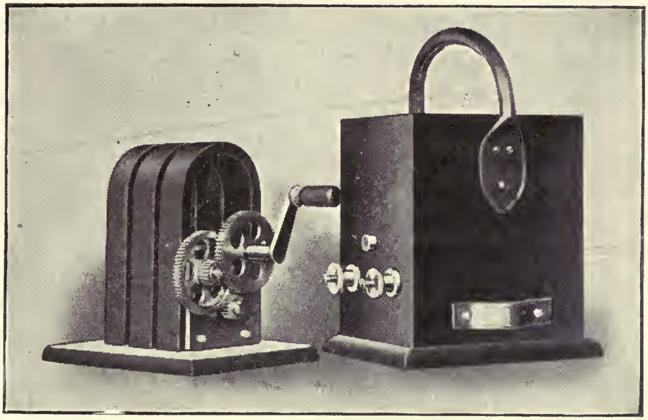


Fig. 32.

placed conveniently near the terminals of the firing line, as shown in the external view of the apparatus.

The pattern from which the illustration (Fig. 32) is taken is made by the British Insulated & Helsby Cables (Ltd.).

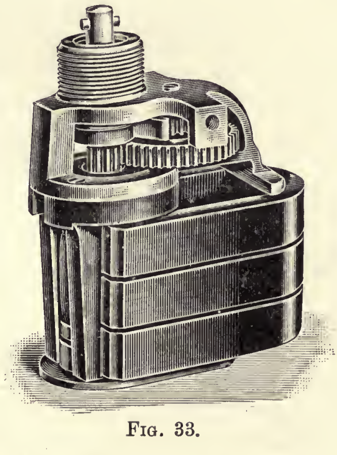


Fig. 33.

In the recently developed and now extensively used Sterling patent magneto exploder (Fig. 33) mechanical energy is transmitted to the armature, through suitable speed-increasing gear, by a single twist, or, more correctly, half-twist, of a detachable T-shaped handle. By a cleverly contrived trip device the wheels are thrown out of gear at the end of the twisting movement, and the armature continues to rotate by its own

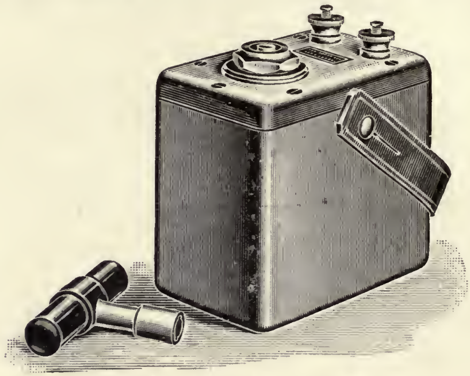


Fig. 34.

momentum. The firing circuit is open until the handle strikes the stop; contact is then made automatically, and, with the armature still revolving freely, the current passes through the firing line and explodes the charge.

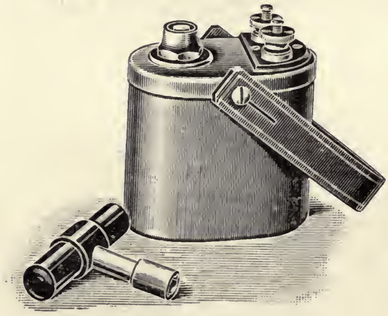


Fig. 35.

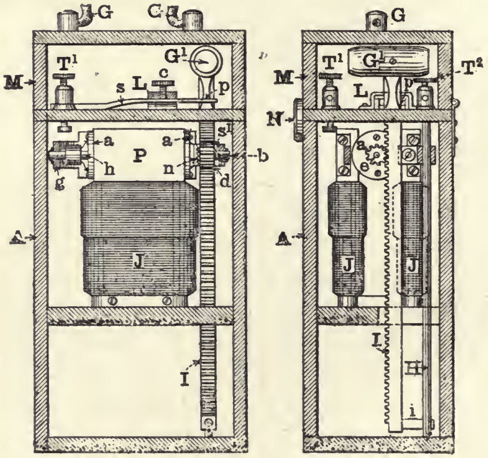
The mechanism of the Sterling machine is encased either in an oak box, as in Fig. 34, or a metal case, as in Fig. 35. The metal-cased pattern has the advantage of being lighter, in the smaller patterns, and is more suitable for use in tropical countries, since it is not liable to shrink and split. The two-shot size (high-tension or low-tension) measures, in oak, $4\frac{3}{4}$ in. $\times$ $2\frac{3}{4}$ in. $\times$ $4\frac{3}{8}$ in. and weighs $3\frac{3}{4}$ lb. In nickel-plated brass case it measures $3\frac{3}{4}$ in. $\times$ $2\frac{1}{4}$ in. $\times$ $3\frac{3}{8}$ in., and weighs 3 lb.

The Explosives in Coal Mines Order of December 17, 1906, Rule 2 (*f*) requires that every electrical firing apparatus shall be provided with a removable handle or safety plug, or push button, which shall not be placed in position or operated until the shot is required to be fired, and which shall be removed or released as soon as a shot has been fired. The removable handle or safety plug shall at all times remain in the personal custody of the shot-firer whilst on duty.

29.—Describe the Principles and Method of Construction of Rack Bar Type Dynamo Exploders.

Dynamo Exploders. These are practically dynamos in miniature, the armatures of which can be revolved by a rotary crank, a pull-over lever, or a vertical rack bar, geared direct, or into a train of wheels in contact with the armature spindle. They are the most efficient and reliable exploders extant and, the weight having been immensely reduced by recently improved methods of design, the smaller sizes are comparable for portability with exploders of any other type.

Figs. 36 and 37 illustrate sectionally the construction of the well-known rack-bar machine. It will be noted by reference to these figures that the circuit-breaking key is placed in the top of the wooden containing case; this modification of an older pattern has been made in order that it may be always kept dry and easily accessible for cleaning. A rod, H, is also provided for guiding and steadying the rack bar I, as shown in the end view (Fig. 37). It is a well-known fact that the field magnet and armature of a small dynamo may be quickly brought to the point of saturation, and that, when the current is at its maximum, the breaking of the circuit causes the entire induced current generated in the coils to be discharged, either through the air at the point of rupture of the current, or through a derived circuit connected with the terminals of the field-magnet. In the exploder under consideration, advantage is taken of this knowledge, and also of the fact that an accelerated is more effective than a uniform rotation of the armature in bringing about magnetic saturation. The mechanism of a rack-bar exploder is as follows: A field magnet, J (Figs. 36 and 37), is formed with soft-iron pole-pieces, P, secured to a yoke, in the usual way, and wound with a predetermined quantity of insulated copper wire. The polar extremities are bored out to receive a Siemens **H**-type armature. Upon the end of the armature shaft *b* is placed a commutator, *h*,



FIGS. 36 AND 37.—"RACK BAR" DYNAMO EXPLODER.

which is touched on diametrically opposite surfaces by a pair of commutator springs (not shown in the illustration), secured to, but insulated from, the yoke. Upon the opposite end of the armature shaft, between the armature and the yoke, is placed a pinion, *d*, provided with a series of ratchet teeth, *n*, on its inner face. These are adapted to engage similar but oppositely arranged teeth, formed on the end of the armature. Between the pinion and the yoke there is placed a spiral spring that tends to press the former forward into engagement with the ratchet teeth *n* of the armature. A rack bar, I, passes through the top of the casing A (which supports the dynamo) and extends downward towards the bottom of the box. At the lower extremity of the rack there is a right-angled arm, *i*, extending from the side of the rack opposite the teeth, which is drilled to slide on a guide rod, H, the latter being secured to the top and bottom of the casing, parallel with the path of the rack bar I. The latter passes between the yoke and the end of the armature, and is held in gear with pinion *e* by a roller journaled in the yoke behind the rack bar. The upper end of the bar, projecting above the top of casing **A**, is provided with a handle, G^1, by which it is moved ; and a pin, *p*, is inserted between the handle and the top of the casing and allowed to project a short distance from each side of the bar. A spring key, *s*, forked at its free end, and embracing the rack bar below the pin *p*, is secured to the top of the case. A bridge, L, extends over the spring key, and is fitted with a contact screw, *c*, which normally touches the back of the key. The armature is wound in the usual way, and the two ends of the winding are connected respectively to each half of the commutating cylinder *h*. The springs (that is, the brushes) which make contact with the surface of the split cylinder are joined in series with the field magnet winding, and the free ends of the latter lead to the binding screws T^1 T^2, upon the top of the containing case. The terminal T^1 is connected electrically with the key, and the terminal T^2 with the bridge. By means of this arrangement of the circuit the field magnet and armature are normally short-circuited. The terminals, handle and key are enclosed by a cover, M, hinged to one side of the box, and shutting down over them. The cover, in turn, is secured in a closed position by a lock, N, and provided with a handle, G, wherewith to carry the machine.

In the operation of firing, the handle is raised, thereby rotating the pinion *e* on the armature shaft without turning the armature, a clutch connection being arranged for this purpose. On pushing down the rack bar, a quickly accelerated rotary motion is imparted to the pinion, thereby rotating the armature and generating a current which passes through the

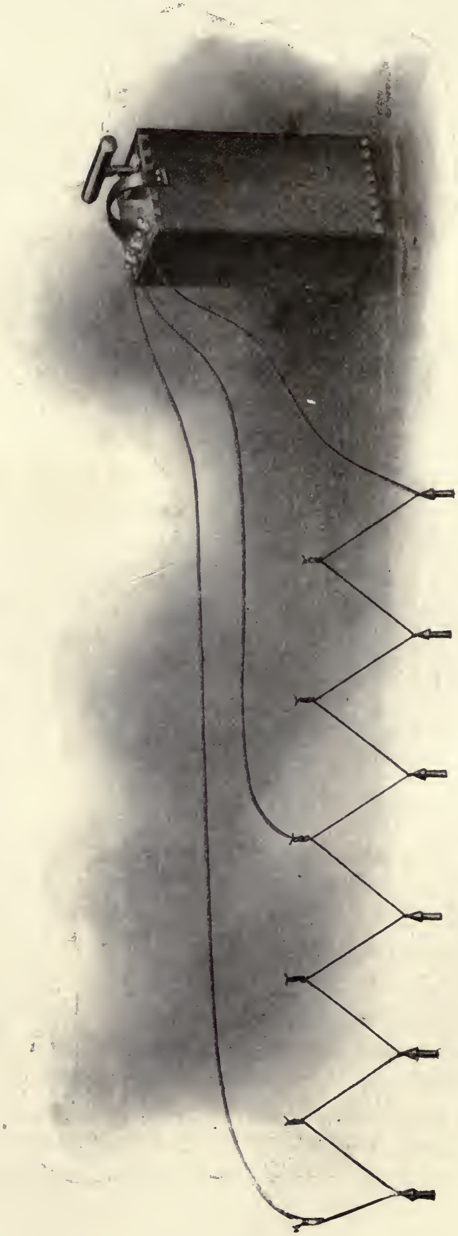


FIG. 38.—NOBEL'S THREE-POST RACK-BAR EXPLODER.

field winding, screws, plates, key, contact screw and yoke. Very little current passes along the external circuit owing to the comparatively low electrical pressure and the high resistance of the firing line. The current produced in this manner increases rapidly as the rack bar descends, and excites the field magnets and armature to saturation—or approximately so—just before the bar reaches the extreme limit of its downward travel. At the point referred to, the pin *p* strikes the spring key *s* and breaks the electrical connection between the screw *c* at the instant the maximum current is reached, so that the extra induced current from the field magnet and armature windings is forced to pass through the external circuit, thus igniting the fuse included therein, and bringing about the explosion of the charge.

As is well known, the superimposed E.M.F. obtained when the circuit of an electromagnet is broken is very much higher than that generated in normal working; and, whereas the direct current from the dynamo could not pass through the external circuit owing to the great resistance of the latter, the superimposed E.M.F. readily enables it to do so as soon as the short-circuit is broken.

In Nobel's three-post rack-bar exploder (Fig. 38) the method of connecting cables when a considerable number of fuses have to be fired is shown. For firing a moderate number of fuses in series, two leading wires need only be used, one of which must be connected with the middle terminal, and the other with either of the side terminals. For firing a large number of fuses and for submarine work, three leading wires should be used; that connected with the middle terminal should be connected at its outer end with a bared portion of the wire joining the fuses together, the joint being afterwards covered with insulating tape.

Firing with Rack-bar Exploder.

In firing with the rack-bar exploder, the handle must be pulled up as far as it will come, and then forced down as quickly as possible. These operations are best performed when both hands are used together.

30.—Describe the Sterling Type of Dynamo Exploder.

The dynamo type of exploder, which may be briefly described as a complete series-wound dynamo in miniature, lends itself by its construction to the production of a fairly large current at a comparatively low pressure, and is, therefore, specially adapted for firing low-tension fuses. In dynamo machines the magnets are freshly excited every time a shot is fired, because the whole of the current generated in the armature passes through the field magnet windings. Thus, the field magnets always retain their strength, and are not affected by vibration, as is the case with the magnets of magneto exploders.

In shot-firing with magneto exploders the circuit is open until the handle strikes the stop, and is then closed. With dynamo exploders it is necessary, by reason of the windings being in series, to close or short-circuit the coils, otherwise the machine will not generate sufficient current. The automatic firing device in the dynamo type, therefore, operates by *opening* the circuit when the handle strikes the stop. The current is then free to flow out on to the line and explode the charge. A greatly increased current is obtained by this method as already explained in connection with the mechanism of a rack-bar exploder.

An exploder of any kind must be simple in operation, light and convenient to carry, capable of withstanding neglect and rough usage, and be unaffected by damp or variation of temperature. These essentials have been met in the Sterling electric blasting machines to a degree hitherto unapproached by any exploder either of English or Continental manufacture. The armature field wires in these machines are insulated with a special enamel covering by an entirely new process, which renders the wire quite impervious to moisture. The field magnets and armature are of the laminated type, built up of thin stampings of iron securely bolted together. This method prevents the formation of eddy currents and ensures instant excitation of the field magnets, and consequently a greatly increased output at the terminals of the machine.

The apparatus is self-contained in its own framing and no parts are held in position by the case. The machine is, therefore, not liable to be put out of operation by warping or injury to the case. The smallest Sterling machine is known as the "BD" type, and is indicated, as to construction, in Fig. 39. It is assembled in the cases as the small magnets shown in Figs. 34 and 35. It will, however, fire three shots through 150 yds. of copper cable, as against two shots for the magneto exploder of the same dimensions.

Another series, of which the general construction is shown in Fig. 40, differ from one another only in their size and capacity.

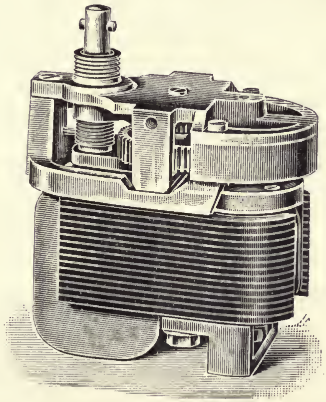


FIG. 39.—STERLING DYNAMO EXPLODER "BD" TYPE.

They are made to fire from 6 to 50 shots and range in weight from 6 lb. to 14 lb.

A novel feature about this type, which is not found in the smaller machines, is the ingenious method adopted for fixing the handle when not in use. This consists of a small curved block into which the stem of the handle is passed. At the base of the block a small knob is recessed, pressed upwards by a spring. The action of this knob is to hold the handle securely in place, and so efficiently does it perform this function that when the handle is placed in the block no amount of shaking will cause it to fall out. The shot-firer will doubtless remember to detach the handle and put it into his pocket when he is preparing to fire a charge. The spring catch described above is shown in Fig. 41, which, however, represents another

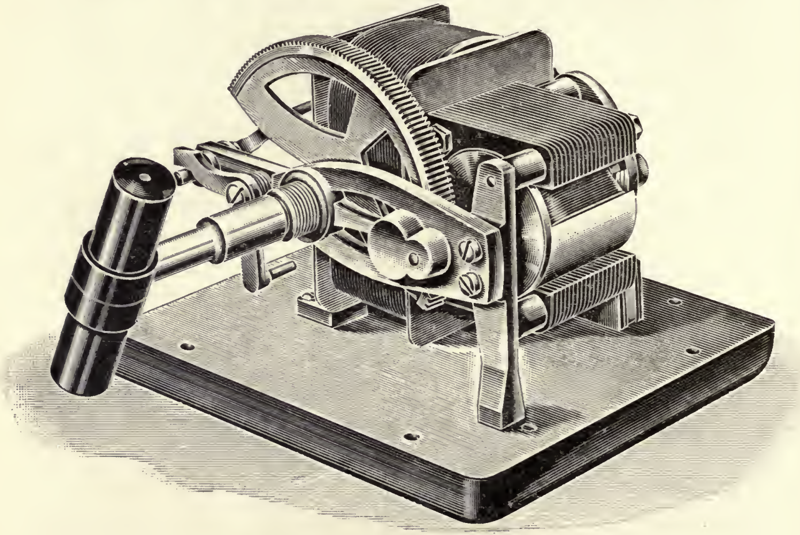


Fig. 40.—Another form of Sterling Dynamo Exploder.

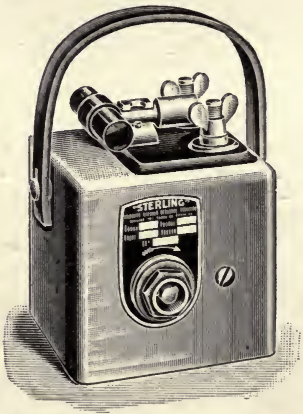


Fig. 41.—Another form of Sterling Dynamo Exploder.

type, with automatic spring-controlled gearing. The small and medium-sized machines are operated by a simple half-twist of the handle, but as the size of the machine increases, difficulty is found in operating the handle owing to the appreciable amount of strength necessary to give it the sharp twist essential to fire the shots successfully. In the larger size, therefore, the method of operation is slightly different. Instead of a sharp twist, the handle is slowly revolved in the direction of the arrow until brought to a stop after half a turn has been made. The hand is then slipped from the handle, and the armature (acting under the pressure of a powerful internal spring) is caused to revolve rapidly until it comes to

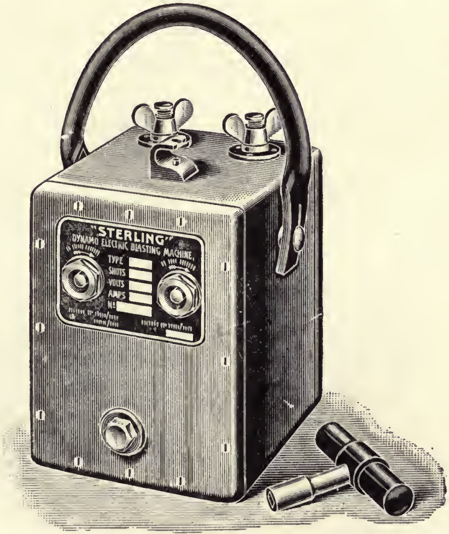


Fig. 42.—The "GF" Type of Sterling Dynamo Exploder.

the position of rest of its own accord. This operation ensures the most perfect results, even with unskilled manipulation, as the act of firing is rendered quite automatic by the action of the spring. The 15-shot size weighs 8 lb.

The Sterling "GF" type (Fig. 42) is designed for the heaviest blasting operations and will fire from 70 to 80 shots in series simultaneously. It is fitted with a safety firing attachment for the prevention of premature explosions. This comprises the powerful internal spring mechanism used in the

15-shot type, but instead of its being set free at the end of the stroke, it is wound up until it will go no further, and is then held in position automatically by a pawl. When all is ready for firing, the key is changed into another hole, at the right of the winding hole, and given a slight turn in the direction of the arrow. This releases the pawl, and allows the spring to actuate the mechanism in the most efficient manner.

This machine, in cast aluminium alloy case, measures $6\frac{3}{4}$ in. $\times$ 5 in. $\times$ $6\frac{3}{8}$ in., and weighs $16\frac{1}{2}$ lb.

Fig. 43.—Pocket Type.

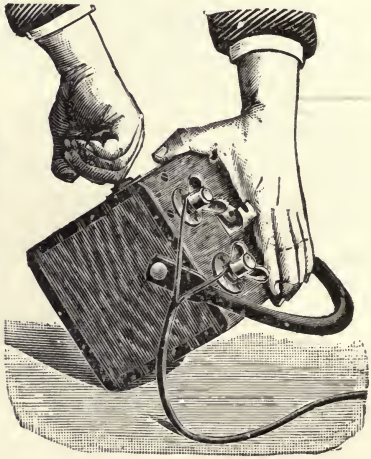


Fig. 44.—Wood-Cased Type.

31.—Describe the Methods of Firing with Sterling Exploders.

Firing with Sterling Exploders.

To fire with the pocket type hold the machine in the left hand as shown in Fig. 43. With the right hand insert the firing key into the socket, and give it a sharp twist to the right. At about a half-turn the contact will strike the stop, when the shots should instantly explode. Considerable force may be used without injuring the mechanism.

With the smaller wood-cased type place the machine on the ground and tilt it to a convenient angle, as shown in Fig. 44.

Place the firing key in the socket and give it a sharp twist, as explained above. A half-turn is all that is necessary.

In the spring controlled type "NF" place the machine on the ground, hold it with the left hand, and insert the firing key into the socket. Turn the handle slowly in the direction of the arrow until it is brought to a stop. Slip the hand quickly from the handle, and allow the latter to return to its normal position. This causes the armature to revolve rapidly, and at the end of the movement the contact is made automatically, firing the shots.

In machines fitted with the safety firing attachment insert the firing key into the left-hand socket and wind up the spring in the direction of the arrow as far as it will go. Remove the key, put it into the right-hand socket, and turn it slightly in the direction of the arrow. This will release the spring and cause the armature to revolve rapidly, and at the end of the movement the contact is made automatically, thus firing the shots.

32.—To what extent are Chemical Exploders available for Shot-firing?

Chemical Exploders.

A low-tension fuse consists, as has been seen, of a pair of wires short-circuited through a metallic connection having about 1 mil (0·001 in.) diameter and $\frac{1}{8}$ in. length. It will be self-evident that such fuses can be ignited by a single primary or secondary cell, providing, of course, that the resistance of the firing line is not excessive (*see* Chap. III., p. 95).

High-tension fuses cannot usually be fired by similar means. The resistance of a high-tension fuse may, however, accidentally coincide with that of a low-tension fuse, in which case it could be fired in the same way. Incaution, arising, no doubt, from the supposition that a high-tension fuse was harmless in the circuit of a low-tension battery, has on several occasions caused accidents.

33.—Explain the Principles involved in the Production of an Electric Current by Chemical Reaction.

Fig. 45 represents an elementary primary cell, comprising a containing vessel, a strip of zinc, a strip of copper and dilute sulphuric acid. The liquid in which the couple is immersed is called the electrolyte. It is absolutely essential to the production of a current that the electrolyte shall be capable of (1) acting chemically on one of the metals of the couple, (2) conducting the current, and (3) being decomposed during the action of the cell. When the two metallic strips are connected outside the liquid by a piece of copper wire, chemical action takes place, and current is said to flow from the strip at which the chemical action is most energetic to that at which activity is least displayed. If a single cell, such as here described, is set up, it will be observed that many bubbles of gas appear on the zinc, and few on the copper strip; hence it is conventional to say that the

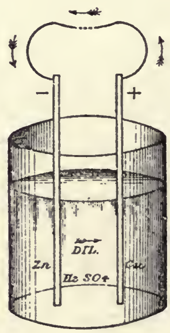


Fig. 45.

current flow is in the direction of zinc to copper, or from the positive (+) to the negative (−) strip. Adhering, for the sake of simplicity, to this convention, let it be supposed that current continues to flow in the same direction, up the copper strip to its terminal, thence through the connecting wire to zinc, and so to the point where it is assumed to start. As the binding screw on the copper strip is +, and that on the zinc strip −, this leads to the apparent anomaly that the positive terminal is on the negative strip, and the negative terminal on the positive strip. If, however, it is noted that inside the cell current flows from the positive plate (zinc) to the negative plate (copper), whilst outside the cell current flows from the positive terminal (copper) to the negative terminal (zinc), this little peculiarity in the nomenclature of batteries at once becomes clear.

Referring again to the rudimentary cell, it is found that the bubbles of gas (which, if collected and tested, would prove to be pure hydrogen) passing from the zinc to the copper have a tendency to stick to the latter plate. This tendency is, for two reasons, detrimental to the working of the cell. In the first place, the bubbles of hydrogen form a film of insulation, which acts as a counter force, increasing the internal resistance of the cell, and thus reducing the available electromotive force. Secondly, a further counter electromotive force is set up owing to the fact that hydrogen has an opposite electrical polarity, in other words, is electropositive, to zinc, and therefore tends to send a current from itself against the working current of the cell. This gaseous action on the plates of voltaic cells is called polarisation. The thousand-and-one modifications in primary-battery construction have, for the most part, been devised with the particular object of overcoming this inherent defect in the transformation of chemical into electrical energy.

Chemical reaction must take place before current can be produced in a primary battery, and as this is impossible in the absence of moisture an absolutely dry cell is unattainable. The expression, *dry cell*, should not, therefore, be taken in its literal sense, but rather as a generic title for all those cells in which the exciting mixture is pasty instead of being fluid, and which are sealed at the top with bitumen, or other convenient preparation. In general, the composition of the exciting and depolarising mixtures are, so far as the mere production of current is concerned, similar to those employed in a common Leclanché cell, but by varying either (or both) the mechanical construction and proportions of ingredients different makers claim special merits for their particular form of cell. Some makes are further improved by the addition of novel depolarising agents.

34.—Describe the Construction of a Dry Cell.

Fig. 46 represents a vertical section through an Obach cell and consists of a zinc cylinder, *A*, fixed on an insulating base, *B*, and containing a central carbon rod, *C*, surrounded by concentric depolarising and exciting mixtures, covered with granulated cork or equivalent material for preventing escape of moisture; the cork being sealed in with a layer of bituminous cement. In the illustration, *A*, is a zinc cylinder cemented to a prepared-asphalt base, *B*. Surrounding a carbon rod, *C*, is a depolarising mixture, *D*, consisting of about 50 or 60 per cent. of manganese peroxide and about 40 or 50 per cent. of plumbago. This is mixed with a gum-tragacanth to the condition of

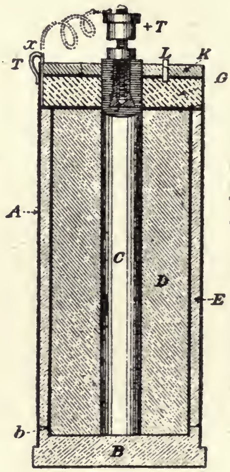


FIG. 46.

a thick paste, which latter is squeezed out of an annular die in the form of a hollow cylindrical column.

A suitable length cut from this column is placed in the cell and centred within the upwardly projecting ring *b* of the base *B* the carbon *C* being previously placed within it. The annular space between the depolariser and the zinc is filled in with an exciting mixture, *E*, consisting of about 80 to 90 per cent. of calcium sulphate and 10 to 20 per cent. of vegetable meal, made into a thin paste with a solution of ammonium chloride. The layer *G* consists of cork, sawdust, or other moisture absorbent, *K* being the black sealing-compound through which is fixed a small glass tube, *L*, to allow the escape of gases.

It is desirable, where dry cells are used, that they should be enclosed in some kind of casing in order to minimise liability to make accidental contact with the firing line. When used in an unprotected condition the negative (—) connection is also liable to touch the positive (+) terminal, as shown in the figure by dotted lines. This, of course, destroys the cell. In the absence of special means of protection the negative wire should be cut off short and bent down, as illustrated at x, Fig. 46.

35.—Describe some Safety Attachments for use with Dry Cells.

One of the best known safety arrangements is that shown in Fig. 47. It consists of a leather case, C, containing dry cells, to the terminals of which there is an attachment known as Wood's patent safety disc. The latter is designed to ensure

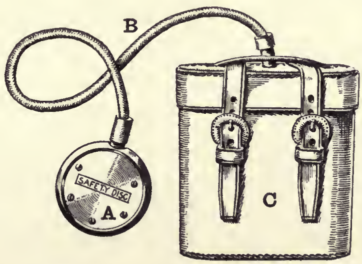


Fig. 47.—Dry Battery Exploder in Case, with Wood's Patent Safety Disc.

that the shot-firing cable shall be totally disconnected from the batteries immediately after the shot has been fired. In the figure referred to, the safely disc A has a brass terminal plate on one side in electrical connection with one pole of the battery through one of the wires in the flexible twin-conductor B. On the other side of the safety disc is a brass terminal plate, slightly convex. Underneath the centre of that plate is a brass pin in electrical connection with the other pole of the battery through one of the wires in the flexible twin-conductor, B. To complete the circuit the convex plate is pressed inwards until it touches the brass pin.

This device was adopted owing to a fatal accident having occurred through a man placing the wires of a twin cable against both sides of the disc of the pattern originally issued, in which each plate was in direct contact. He was showing a man standing beside him (who was holding a primed Roburite cartridge in his hand, and all connections completed) how to fire the shot, and thoughtlessly placed the wires against each side of the disc.

Messrs. Wood then adopted this device, which necessitates pressure on one side of the disc to complete the circuit.

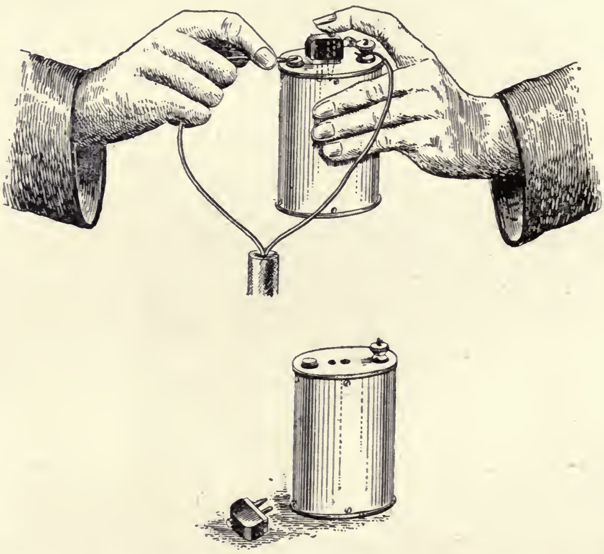


Fig. 48.—Davis Pocket Shot-Firer, with Safety Key.

It will be seen that a predetermined and deliberate action on the part of the operator is necessary to bring the free end of the cable into electrical connection with the safety disc. The apparatus has a shot-firing capacity of about 2,500 shots, and weighs less than 2 lb.

Messrs. Davis and Son have recently designed a dry battery shot-firer to meet the demand for a specially portable form of apparatus. This battery is contained in an aluminium case of the form shown in Fig. 48. To comply with the rule regulating the use of dry battery exploders in mines an ingeniously arranged detachable press-button or firing-key is provided, which is calculated to render impossible an accidental or too hasty ignition of the fuse.

At many collieries one, two or three dry cells are grouped together in a pinewood box with screw-down lid. The outside + and − wires are respectively joined to two terminals bolted through one side of the case, and the exploder completed by the addition of a firing key and a handle or sling strap.

Messrs. Nobel supply a belt battery for use with their low-tension fuses which consists of a military-pattern belt carrying a leather pouch with two small dry cells.

In order to comply with the Explosives in Coal Mines Order, dry-cell sets must be fitted with a firing-key.

Particulars of a number of dry cells are given for convenience of reference in Table IV.

36.—Give Data for Guidance in the Selection of Cells.

The following facts may serve for guidance in the selection of cells to work under any given conditions: The E.M.F. is the same for all cells of the same type, irrespective of size. The E.M.F. of any number of cells joined in parallel is equal to that of one cell only. The E.M.F. of any number of cells joined in series is equal to that of one cell multiplied by the number of cells so joined. The larger the cell the greater the number of shots that it will fire before exhaustion ensues. The smaller the cell the greater its internal resistance, and therefore the less energy available for overcoming the resistance of line and fuse. Joining cells in parallel is practically equivalent to increasing the size of a cell. Joining cells in series permits of a greater number of shots being fired simultaneously, or of firing a lesser number over a longer or lighter line.

37.—What is an Accumulator, or Secondary Battery, and how does it produce Current?

In the early part of the nineteenth century, the French physicist Prof. Gautherot, whilst engaged in decomposing acidu-

Table IV.—*Dimensions and other Particulars of Dry Cell Exploders.*

No.	Type of exploder.	Dimensions.		Electro-motive force, about.	Internal resistance, about.	Weight.			Average number of low-tension fuses in series.
		Inches.	Millimetres.	Volts.	Ohms	Lb.	oz.	Kilogs	
1	Davis 12 cells battery	$7 \times 4\frac{1}{2} \times 4\frac{3}{4}$	178 × 114 × 121	15·0	6·0	8	0	3·63	3 to 4
2	,, 6 ,, ...	$5\frac{1}{4} \times 2\frac{3}{4} \times 4\frac{3}{4}$	133 × 70 × 121	9·0	3·0	4	0	1·80	2
3	,, 3 ,, ...	$5\frac{3}{4} \times 5\frac{3}{4} \times 2\frac{1}{2}$	146 × 146 × 63	4·5	1·5	4	12	2·15	1
4	,, 3 ,, ...	$4\frac{1}{2} \times 1\frac{3}{4} \times 4\frac{3}{4}$	114 × 44 × 121	4·5	1·5	2	0	0·90	1
5	E.C.C. (Burnley cells)	$3\frac{1}{4}$ diam. $\times 8$	82 diam. × 203	1·47 to 1·5	0·35	4	$3\frac{1}{2}$	1·91	1
6	,, ,, ...	$2\frac{1}{2}$,, $\times 7$	63 ,, × 178	,, ,,	0·70	2	12	1·24	1
7	,, ,, ...	$2\frac{1}{4}$,, $\times 5\frac{7}{8}$	57 ,, × 149	,, ,,	0·85	1	5	0·51	1
8	Obach cell	$2\frac{13}{16} \times 2\frac{13}{16} \times 6\frac{1}{2}$	72 × 72 × 165	,, ,,	0·20	3	0	1·36	1
9	,, ,, ...	$2\frac{11}{16}$ diam. $\times 7\frac{1}{4}$	68 diam. × 184	,, ,,	0·20	2	12	1·24	1
10	,, ,, ...	$2\frac{3}{16}$,, $\times 6$	55 ,, × 152	,, ,,	0·25	1	6	0·62	1
11	,, ,, ...	$1\frac{15}{16}$,, $\times 5\frac{1}{4}$	49 ,, × 133	,, ,,	0·30	1	0	0·45	1
12	,, ,, ...	$2 \times 2 \times 5\frac{1}{2}$	51 × 51 × 140	,, ,,	0·25	1	6	0·62	1

lated water by passing an electric current into it through the usual medium of two platinum plates, observed an hitherto unnoticed phenomenon. He discovered, in fact, that the platinum plates, if tested immediately after disconnecting from the original source of electrical energy, themselves gave out a feeble current, but in a direction the reverse of the initial current. It was at first supposed (as it is, popularly, at this moment) that the plates absorbed current during the preliminary or charging operation and gave it up again during discharge. But Prof. Becquerel, at a later date, disposed of this hypothesis by demonstrating that the returned current was due not to storage of electricity but to the presence of substances having chemical affinities for each other, derived from decomposition going on during the charge. This returned current is now called the secondary current, and the phenomenon thus briefly set forth constitutes the fundamental principle of secondary cells, also known, in popular language, as accumulators or storage batteries, or reversible cells.

Secondary Battery Exploders.

The following simple experiment conveys a tolerably accurate idea of the formation process and the reactions that take place in a secondary cell: If two sheets of ordinary lead be placed slightly apart in diluted sulphuric acid, and a current be sent through them, a dark brown deposit will form upon the plate connected to the positive pole of the charging battery, due to the formation of peroxide of lead on the surface of that plate, whilst the other will be reduced slightly to spongy or porous lead. Upon disconnecting these plates from the charging source, and joining through a galvanometer circuit, a current will be shown to flow from the brown or peroxidised to the other reduced plate. The result of discharging is the reduction of peroxide of lead on the one plate to oxide, and then to sulphate of lead (from the presence of the sulphuric acid in solution), and of the spongy lead on the other to sulphate of lead. Upon recharging, the anode or brown plate, attached to the positive pole of the charging source, will again become peroxidised, and the cathode or other plate reduced to spongy lead; the sulphate of lead will thus disappear from both plates. The plates are in this manner continually oxidised and deoxidised as they are charged and discharged.

38.—Are Accumulators much used for Shot-firing?

Accumulator cells have not so far been used for shot-firing to any great extent. A shot-firing "battery" must withstand rough treatment and perhaps an occasional fall. Portable accumulator cells are more or less of necessity enclosed in easily-damaged cases. Leakage of acid, corrosion of terminals and cost of upkeep add to the difficulties in the way of their adoption.

Size for size an accumulator will fire a considerably greater number of shots than a dry battery, and if suitably designed for the purpose in view such exploders should prove very serviceable.

39.—What attention is necessary to ensure the satisfactory working of Accumulator Cells?

Every secondary shot-firing cell should be tested daily, by means of an accurately-calibrated low-reading voltmeter. If the P.D. at its terminals is shown to be 1·85 volts or lower, the cell should be set aside for charging. To this end the ebonite-plugs are removed and each compartment of the battery is filled with sulphuric acid, diluted with water to a specific gravity of 1·175 to 1·180. The proper strength is ascertained by means of a hydrometer: that of Beaumé, for example, would read 22 degs. to correspond with the above-named specific gravity.

It is important that the polarity of the mains be ascertained before placing a cell in circuit, for a charge in the wrong direction will ruin the plates if not discovered and remedied very quickly.*

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* There are several methods of ascertaining the polarity of electrical mains. A direct-reading indicator may be obtained, in which a pointer indicates "positive" or "negative" on a dial when simply joined across the mains.

Another pole tester consists of a small glass tube, capped and fitted with a terminal at each end. Within are two small knobs, immersed in a liquid. Before using both knobs are bright, and after using the negative end becomes purple. After a test, the normal conditions are restored, so that the apparatus is always ready for use.

A third method involves the use of chemically-prepared strips, known as pole-finding papers, which are sent out in the form of small books similar to the litmus and turmeric books used in chemical laboratories. To make a test, a strip is torn from the book, damped slightly on the tongue, and the wire extremities applied to it, about 1 in. distant from each other. Some papers show a bright red mark at the negative contact.

Charging is continued until the electrolyte appears in a state of vigorous effervescence. If the cell is of a design that will admit a small hydrometer, the state of charge may be best ascertained with that instrument. A discharged cell may have an acid density of 1·150 (it should not be allowed to fall below this), while during charging the density will gradually rise, until when fully charged it reaches a maximum limit of 1·200. If, as is usually the case with accumulator shot-firers, it is impracticable to make a hydrometer test, the voltage should be ascertained, remembering that a newly-charged cell (of any type except lithanode) gives a voltage 0·5 higher than the normal. This, however, gradually falls off, leaving the normal voltage of 2 to 2·1 after the first discharge.

It is desirable that all secondary cells should receive a good charge at least once in a fortnight, even though they may have remained idle in the interim. Cells are injured by being partially charged and then exhausted, but overcharging does no harm. Indeed an occasional charge prolonged for several hours after the electrolyte appears to boil is advantageous, provided, of course, that the proper current-density is not exceeded. If on applying the back of the hand to a cell case there is any perceptible warmth, this may be taken as an indication that the charging current is too heavy.

40.—Describe an Apparatus suitable for charging Accumulators.

Messrs. Everett, Edgcumbe & Co. have designed the charging set shown in Fig. 49 to charge motor-ignition cells from direct-current mains of any voltage. It is, of course,

others a brown mark where touched by the positive wire. Confusion and consequent mistakes will be avoided, however, if polarity be ascertained in the following manner: To one wire leading from a main attach a strip of lead, previously scraped bright all over. Next attach two short wires to an incandescent lamp (of the kind used on the installation) and join the free extremities to another cleaned leaden strip and the opposite main respectively. If now the two lead strips are held in dilute sulphuric acid for a few moments a current will pass through the lamp and the liquid, and that strip attached to the positive main will be observed to turn brown. (*Vide* experiment described on next page.)

equally applicable to secondary-cell exploders, there being no difference between one and the other except in the matter of protecting cases and contact keys.

The apparatus consists of two lamp holders, current direction indicator, adaptor for making connection with any electric light fitting, ammeter reading to 2½ or 5 amperes as preferred, flexible connections, &c., in a closed walnut box with carrying handle for travelling.

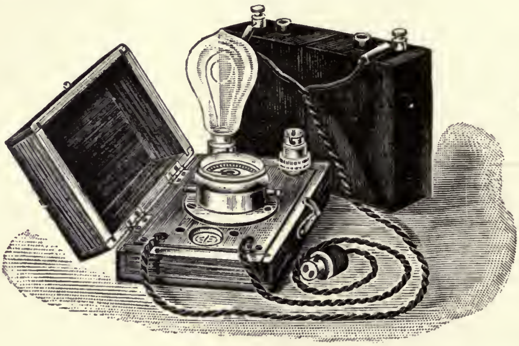

Fig. 49.

41.—How are Pole-finding Papers (for testing the Polarity of Electric Wires) prepared?

The two following methods were recently given in the *Scientific American*:—

First method: Dissolve sodium sulphate, a teaspoonful, in ½ pint of water, in which also dissolve about the same quantity of potassium iodide and of starch. To dissolve the starch the water must be heated. Soak white blotting paper in this solution and dry it. Cut it into strips of any convenient size; ½ in. by 2 in. is suitable. Keep the paper in a dry place such as a tin box or a glass bottle. To use, moisten a strip and place the two poles upon it, nearer together or farther apart according to the voltage of the current. A dark spot will appear at the *positive* pole. Second method: Dissolve 15 grains of phenol-phthalein in ½ oz. of common alcohol. Dissolve also 20 grains of sodium sulphate in 4 oz. of water. Soak blotting paper in the first solution and drain off the superfluous liquid. Then soak it in the second solution and dry it. Afterwards treat it in the same manner as in the first method. A red spot appears at the *negative* pole.

It is useful to note that on a high-voltage supply, say, from 200 to 240 volts, an 8 c.p. lamp will pass about $\frac{1}{6}$ ampere, a 16 c.p. lamp about $\frac{1}{3}$ ampere, and a 32 c.p. lamp about $\frac{2}{3}$ ampere. On a low-voltage circuit—that is to say, from 100 to 120 volts—the currents passed will be approximately double those given.

It should be remembered that a current of 1 ampere flowing for one hour is equivalent to a current of $\frac{1}{2}$ ampere for two hours, or to 2 amperes for half an hour, and so on.

Chapter II.—PART II.

CONNECTING WIRES FOR SHOT-FIRING CIRCUITS.

42.—Explain the meaning of the terms *Conductor, Insulator, Resistance,* and show the Resistance of Different Substances as compared with Copper.

In order to place a safe distance between a blasting charge and the operator it is necessary to establish a means of electrical communication across the intervening space. Formerly iron wires were used for this purpose, while in those parts of Europe where frictional exploders continue to be used brass wire is frequently employed. In all modern blasting equipments copper wire is the most suitable and is the only kind readily obtainable with an insulated covering. The reason for this will be apparent when it is remembered that metals vary widely in their relative powers of conducting electricity, or, as it is usually expressed, they have different conductivities. The difference, in fact, between a conductor (which is a substance capable of conveying an electric current) and an insulator (which is a substance incapable—under ordinary conditions—of conveying an electric current) is only one of degree. Table V. indicates a few substances in descending order of conductivity, commencing with the best known conductor of electricity—silver—and ending with the worst known conductor (that is, the best known insulator)—dry air :—

Table V.

Good Conductors.	*Partial Conductors.*	*Insulators.*
Silver.	Water.	Oils.
Copper.	Bodies of animals.	Porcelain.
Aluminium.	Linen.	Wool.
Gold.	Cotton	Silk.
Other metals.	Hemp.	Resin.
Gas-coke.	Mahogany.	Gutta-percha.
Charcoal.	Pine.	Shellac.
Graphite.	Rosewood.	Ebonite.
Strong acids.	Lignum vitæ.	Paraffin.
Metallic ores.	Teak.	Glass.
Moist earth.	Marble.	Dry air.

The quality of a conductor, in virtue of which it opposes the passage of an electric current, is called its *resistance*, and *in any given wire of uniform cross-section is directly proportional to the length, and inversely proportional to the sectional area of the conductor.* From this it is seen that resistance may be increased either by increasing the length or by decreasing the diameter of a conductor. It is also increased if any other metal (except silver) be substituted for copper: the relative resistances of different substances being approximately shown in Table VI.

Table VI.—*Showing the Approximate Resistance of Different Substances compared with Copper.*

Copper	1
Aluminium	2
Zinc (pressed)	3½
Platinum	5
Phosphor-bronze	5⅓
Iron	6
German silver (Cu4, Ni2, Zn1)	13¼
Platinum silver (Pt33, Ag66)	16¾
Platinum iridium (Pt80, Ir20)	18⅓
Manganin (Cu70, Mn12, Ni4)	26
Platinoid (German silver + 1 or 2 per cent. of tungsten)	27¼
Mercury	59
Arc-light carbon	4,400
Pure water at 18°C.	2·3 billions.
Bohemian glass	40 trillions.
Ebonite	187 ,,
Gutta-percha	300 ,,

The lower part of Table VI. serves to show the vast difference in resistance between any of the metals and the substances termed insulators. A piece of gutta-percha, for example, offers

300 trillion times as much opposition to the passage of a current as a piece of copper of equal length and cross-section.

The practical outcome of the fact that a good conductor has a relatively small resistance and a good insulator a relatively great resistance is found in the facility with which an easy path may thereby be provided for the electric current, and be surrounded with insulation to prevent or minimise loss by leakage to earth.

43.—Describe some "Cables" or Conductors suitable for Shot-firing.

Conductors for shot-firing circuits are composed of single wires, or of a number of wires twisted together to form a small cable. The latter type have the advantage of greater flexibility and consequent lessened liability to rupture in the necessarily frequent coiling and uncoiling of the firing line. A stranded cable will also withstand blows from pieces of coal or rock and other rough treatment much better than a solid wire, and is in every respect decidedly preferable for all blasting circuits.

These wires, whether solid or stranded, are variously insulated, cotton, jute, paraffin, ozokerite, indiarubber and guttapercha being the materials chiefly employed for the purpose.

For convenience of manipulation the two wires necessary to complete a circuit are frequently insulated and then enclosed side by side in a strong braiding, the double wire being known as a twin cable.

In other patterns, insulated wires are twisted spirally and braided over all in such a manner as to form a circular twin cable.

If one set of strands are laid spirally around the insulation covering an inner conductor, and then braided or otherwise covered over all, a concentric cable is formed.

Details of 10 varieties of cable specially suitable for blasting circuits are given in Table VII., to which the following explanations refer :—

Column I. indicates the size of wire according to the legal standard wire gauge. No. 1 specimen, *e.g.*, is marked 3/22 (sometimes written 3·22), meaning a three-stranded cable of which each wire is No. 22 standard wire gauge (S.W.G. or L.S.G., Legal Standard Gauge, or I.S.G., Imperial Standard

Table VII.

No.	I. S.W.G.	II. Specification.	III. Diameters. Wires. Inch.	Wires. Mm.	Strand. Inch.	Strand. Mm.	Finished. Inch.	Finished. Mm.	IV. Resist'nce per double yd. Ohms.	V. Weight per double yd. lbs.	VI. Length per lb. Yards.	VII. Length per kg. Metres
1	3/22	Three-strand conductor, covered with guttapercha to No. 8 S.W.G., longitudinal warps, strong braid, then drawn through preservative composition	0·028	0·711	0·059	1·500	0·240	6·1	0 2650	0·156	6·41	12·9
2	4/25	Flat twin conductor, each covered with guttapercha to No. 12. S.W.G., laid together, taped and braided over all, and served with preservative composition	0 020	0·508	0 045	1·143	0·310 by 0·200	7·8 by 5·0	0·0390	0·065	15·38	31·0
3	3/22	Three-strand tinned conductor, covered with pure and vulcanising rubber and proof-tape, all thoroughly vulcanised together, braided and served with preservative compound, and then armoured with galvanised wire braiding	0·028	0·711	0·056	1·422	0·192	4·8	0·0265	0·354	2·82	5·7
4	4/25	Four-strand twin circular conductor, each insulated as in specification (3), the two laid together, wormed, braided and covered with preservative compound	0·020	0·508	0·045	1·143	0·260	6·6	0·0390	0·110	9·09	18·3
5	4/25	As in specification (4), but outer covering consisting of plain cotton braid, without preservative compound	0·020	0·508	0 045	1·143	0·265	6·7	0 0390	0·092	10 87	21·9
6	4/25	Four-strand flat twin conductor, insulated as in specification (4), then laid together, braided and compounded black	0·020	0·508	0·045	1·143	0·265 by 0·175	6·7 by 4·4	0 0390	0 090	11·11	22·4
7	3/22	Two three-strand tinned copper conductors, each double-cotton covered and served, then covered with one layer of pure indiarubber, one of proofed tape, braiding and preservative compound, and afterwards twisted together	0·028	0·711	0·056	1·422	0 330	8·3	0·0265	0·092	10·87	21 9
8	3/22	Three-strand plain copper twin conductor, double cotton-covered, one layer of pure indiarubber, braided, the two laid together, braided over all, and served with preservative compound	0·028	0·711	0·056	1·422	0·283 by 0·146	7·1 by 3 7	0·0265	0·082	12·19	24·5
9	7/29	Seven-strand plain copper concentric conductor, insulated with pure indiarubber and proofed tapes, braided over all, and served with ozokerite	0·013	0·033	0·013 to each conductor	0·033	0·290	7·3	0·0480	0·085	11·76	23·7
10	1/22	Single-strand plain copper twin conductor, each wire double-cotton covered and paraffined, the two then laid together, braided over all, and paraffined	0·028	0·711	0·028	0·711	0·185 by 0·110	4·7 by 2·8	0·0794	0·030	33·33	67·2

Gauge). Similarly, 4/25 implies four No. 25 S.W.G. wires stranded together.

Column II. contains details of insulations suited to various classes of work. Nos. 1 to 6 have gutta-percha or vulcanised rubber coatings, and are most suitable for use in wet places, or

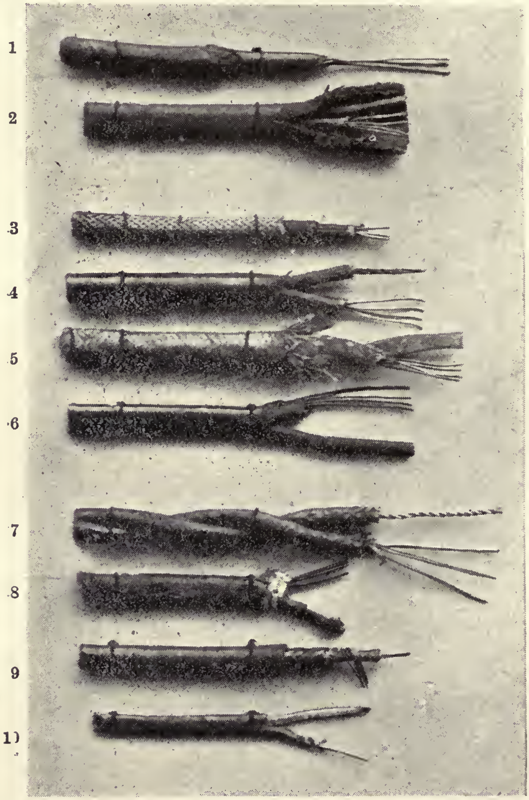

Fig. 50.—Conductors for Blasting Circuits.

wherever a highly insulated cable is necessary. No. 5 is a high-class cable, suitable for high-tension blasting, but is not so well adapted for heavy work as the others with similar insulation. It is, however, sometimes strengthened mechanically by the addition of an outer galvanised wire armouring.

No. 7 gives particulars of a low-tension firing cable which has proved most satisfactory and economical for all underground work. A cable of this kind, though heavier than those more commonly used, possesses greater wearing capabilities, and it is not so liable to short-circuit as a twin wire enclosed in a single outer covering. No. 8 specification has the same conductivity per unit of length, and is the pattern commonly employed with low-tension exploders. No. 9 is a concentric cable the conductors in which are composed of very fine wires. This makes it exceptionally flexible and well adapted for working off a small reel or drum. No. 10 has two No. 22 standard wire gauge wires separately insulated and then braided over all. It is suitable for use with any magneto on dynamo exploder, but is obviously not so durable as the others enumerated in the table.

Column III. in the table gives diameters from which the dimensions of a drum necessary to hold a given length of wire may be ascertained.

Column IV. indicates the resistance per double yard—that is, the resistance per yard out and return, or the resistance per 2 yds. of single cable.

Columns V. and VI. show the weight per double yard and the number of yards per pound of cable respectively.

Column VII. gives the metrical equivalent of the figures in Column VI.

Illustrations of the wires referred to in the preceding table are shown in Fig. 50, the uppermost cable corresponding with No. 1 in the list.

44.—Explain the Proper Method of Paying Out and Taking Up a Shot-firing "Cable."

Uncoiling and Coiling Shot-firing Wires.

Unless a shot firer has received special instructions, he is scarcely ever seen to handle a coil of wire in a workmanlike manner. He will commonly be observed to take up his 40 or 50 yard length of twin cable in one hand, separate two or three coils at a time with the other, and drop them on the ground.

When the line is pulled the rings may spiral out straight, but, more often than not, the line closes on itself and forms a kink. If the kink is noticed by the shot firer, he will give the line a vigorous pull to straighten it out, regardless of the fact that his method is precisely that which a man would adopt if he were required to break a wire with his hands.

The damage caused to a shot-firing wire by this thoughtless treatment is certain to result in breaks sooner or later, and these breaks are all the more troublesome because they may occur without apparent injury to the insulation, and can then only be found by testing or carefully feeling along the line.

To pay out a cable in the proper way the end is made fast (to the fuse wires), the coil gripped by one hand and rotated clockwise (as though it were a wheel on a spindle) as far forward as the hand will take it. At the end of the forward movement the coil is seized at the point nearest the body by the other hand, which continues the motion, each hand alternately taking the other's position.

As the cable falls to the ground the operator walks away from it—backwards, if he can conveniently do so—and leaves the line lying straight out before him.

To coil a line one end is first turned into a ring of about 18 in. or 2 ft. diameter, and tied. The tying is important, for if the first circle is not made secure the end will work loose and make the proper coiling of the line impossible. When the first ring has been formed it is rotated as already described, but *towards* the body instead of from it, the operator meanwhile advancing in the direction of the shot hole.

45.—Show How and Why Joints in Wires should be Properly Made.

Joining and Insulating Wires.

When a shot-firer who has not acquired any elementary electrical information is requested to join two pieces of wire together he almost invariably does it as illustrated in Fig. 51(A). Wires so joined can probably be relied upon not to pull apart, but the question of electrical conductivity is entirely overlooked. It would be possible for two wires thus looped together to lie on the ground without touching one another, and even if tightly strained the area of contact would obviously be very small.

Every joint increases the resistance of a line and consequently reduces the amount of current available at the battery for firing the charge.

A joint on a current-carrying wire must be sound both mechanically and electrically. On all sizes generally used for shot-firing a joint is made by laying the bare ends across one another in the position of a widely opened pair of scissors. Each wire is then turned not less than six times over the other one, as seen partly done in Fig. 51(B) and completed in Fig. 52.

It is important to remember that the wire ends must be cleaned and rubbed bright with emery cloth before being twisted together, and that they should not be "nicked" by the knife when paring off insulation.

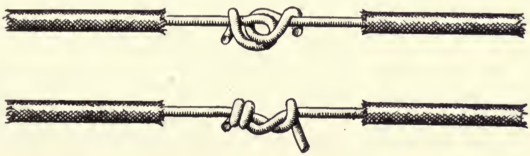

Fig. 51.

46.—Describe How a Joint should be Soldered and Insulated.

When a joint is intended to be permanent, as, for example, in making up a new line from short but undamaged pieces of an old cable, the junction must be made as above, soldered, and then insulated. In soldering, soft solder should be used and the joint thoroughly permeated with it and made homogeneous. It should be cleanly finished and free from sharp points either of wire ends or solder. It is contrary to all fire insurance and other electrical rules to use any flux for joint-making except resin, or resin dissolved in methylated spirit.

Joints are very easily soldered, providing care is taken to rub all the wires with glass or emery paper until they are as bright as they can be made. The splice must then be made by using two pairs of pliers. The use of the fingers is fatal to easy soldering.

To insulate a joint cut away the coverings, as in Fig. 52—braiding, tape, vulcanised and pure rubber—one by one with a sharp knife for the distance required for making the joint and leave the insulation clean and tapered and free from fibres.

Take a lenght of prepared indiarubber splice, and, commencing from one side of the joint, wrap the strip spirally round the wire with an overlap until the rubber is reached and covered; then, after slight warming (with a spirit lamp or match), return, wrapping in the opposite direction, thus ending off at the same side of the joint from which it started.

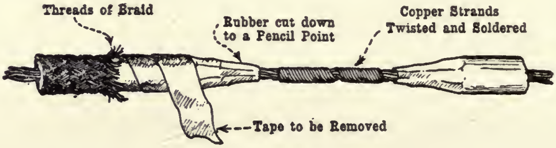

Fig. 52.

After the splice or strip is wound on, two independent layers of adhesive tape should be laid on over all, the lower layer covering all the exposed rubber strip, and the upper layer covering, in addition, 1 in. at each end of the braiding.

Chapter II.—PART III.

TESTING.

47.—Admitting that it is Dangerous to use Explosives in Fiery or Dusty Places in Mines, and that some Explosives are Safer than others in Explosive Atmospheres, what means are provided for separating the more from the less safe Blasting Agents?

Stations have been established in various countries for the purpose of testing explosives and such as pass certain prescribed tests are classed as "safety" or "permitted" explosives.

48.—Is there any Absolute Test of Safety for Explosives?

No. It is at present impossible to get an explosive which will be absolutely safe under all conditions. H.M. Inspectors have frequently reported that "it cannot be too strongly impressed on the users of these (permitted) explosives that all that can be really claimed for them is that they are less dangerous than gunpowder so far as the ignition of firedamp and coal dust is concerned. The misnomer ('safety,' as applied to permitted explosives) seems to have caused some users to imagine that these explosives are safer under all conditions, in total opposition to the true facts of the case, that they are absolutely dangerous unless used with certain definite precautions." There is not a single explosive on the "permitted list" which has not at some time or other caused an explosion of the gas at the testing station when fired without stemming.

49.—What Method of Testing Explosives for Safety is practised in England?

The English, more generally known as the Woolwich, test consists in reproducing, so far as is practicable, the conditions which obtain in actual work. The shots are fired from a steel cannon into an explosive mixture of coal-gas and air.

Each charge is stemmed with dry clay, this selection having been made in order to secure uniformity in the conditions of the test. If 20 charges of any sample are fired into the explosive mixture, under certain specified conditions as to weight and stemming, without causing ignition, the explosive is then entitled to be placed on the "permitted list."

50.—Is it a Fair Test of Safety to "Fire" an Explosive in a Gas Mixture formed of Coal-Gas from a Town Supply?

Yes. Whatever error there may be is on the side of safety because coal gas mixtures are more sensitive to ignition, and therefore the test is made in a more dangerous gas than is found in mines.

51.—What is the French Method of testing Explosives for Safety?

The French method consists in calculating the temperature produced by the explosion of each explosive which is submitted for testing and passing it for use in mines if the temperature does not exceed a certain point.

52.—Explain the Austrian Method of testing Explosives for Safety.

In Austria the cartridge to be tested is placed on the top of a lead block and surrounded by an atmosphere of between 7 and 8 per cent. of pit gas which is drawn from a working colliery and purified, the remainder of the mixture being air.

The cartridge is then detonated, and if there is an ignition of the inflammable mixture the weight of the charge is reduced and the experiment repeated until a certain charge is found that will not fire the inflammable mixture.

53.—How are the Belgian and German Tests for Safety conducted?

In Belgium and Germany the explosive to be tested is fired from a steel gun into a wooden gallery (which is 6ft. high and 4 ft. 6 in. wide) containing an 8 per cent. explosive mixture of pit gas and air. No stemming is used, therein differing from the English test.

54.—How would you Test the Practical Efficiency of a Batch of Detonators?

A simple method is to fire a few detonators on separate sheets of lead, in the open air. The quality of the detonator is revealed by examination of the sheets.

55.—What Advantages are there in Testing Fuses, and How should Tests be Made?

The facility with which the condition of the several parts of an electric blasting circuit can be ascertained at any time up to the moment of firing constitutes one of the special advantages of this method of blasting, as compared with ignition by tape fuse or friction igniters. The several parts which make up a blasting circuit have, however, now reached such a high state of practical efficiency that it is only during the development of important and large scale blasting operations that preliminary testing becomes either necessary or desirable. In the routine practice of shot firing in a coal mine more time would be wasted in testing fuses and circuits than is required to fire several shots. In mines where exceptional precautions for the prevention of explosions are considered to be necessary, special arrangements are made to secure that fuses and shot-firing apparatus shall be tested before going down the mine.

Testing Fuses. It is generally considered that the principal advantage possessed by low-tension over high-tension fuses is that the former may be tested for continuity before firing. It is doubtful, however, whether the supposed advantage is of so much importance as is frequently assumed. On the average there is probably not more than one defective fuse per thousand issued, and it may well be that the defect in that one cannot be ascertained by testing. That a continuity test is not necessarily evidence that a fuse answering to it will fire may be seen by reference to Fig. 53, which has been drawn from an actual sample.

The appliances required for the purpose of testing fuses comprise: (1) A suitable source of current, (2) some means of indicating current flow, and (3) adequate protection of the operator from injury caused by untoward explosion of the detonator fuse under test.

Fig. 53.—Showing Bridge of Low-tension Fuse "shunted" by Short-circuiting of Connecting Wires in Fuse Head.

The apparatus must be so constituted as to be incapable of sending sufficient current through a fuse to cause its ignition. This end can be readily attained, while allowing considerable latitude in choice of means. Thus, a very weak cell, itself incapable of firing a fuse, may be used in conjunction with a common detector galvanometer which interposes but trifling additional resistance in the circuit; or, on the other hand, any form of shot-firing cell may be employed in connection with a high-resistance galvanometer or voltmeter offering opposition sufficient to reduce the battery current below an intensity at which a fuse might ignite.

It should be remembered that any primary cell in good order will explode a fuse. Consequently, the battery used for testing must either be run down, or a resistance must be inserted in the testing circuit. A simple method of testing fuses without a galvanometer is to join each one (or a group if preferred) in series with a single Leclanché cell and a long-distance electric bell, or a telephone receiver. Vibration of the bell hammer or buzzing in the telephone indicates electrical continuity. Conversely, absence of sound is an indication of rupture some-where in the circuit, and may be taken to imply a defective fuse bridge, provided that all other parts of the circuit are known to be intact.

A magneto-telephone (bell circuit) is often used as a substitute for a high-tension exploder, and it is, therefore, scarcely necessary to observe that such an instrument should not be used for testing.

Some high-tension fuses may be tested with comparative ease by circuiting a current through them from a low-tension magneto exploder in series with a suitable galvanometer. The exploder firing-key should be temporarily fastened down, and the handle turned slowly when making a test.

Other high-tension fuses are not so readily tested, and may, in some cases, require apparatus not usually available at a colliery. As a rule, although the conductivity of the bridging composition may often be ascertained by means of a long, distance magneto-telephone, the testing of high-tension fuses is not considered practical.

In all fuse-testing operations personal protection against the possible explosion of a detonator is imperatively necessary.

It is sometimes claimed that if a testing circuit is arranged so as to pass only a minute current there is no danger of ignition, but although careful choice of apparatus may do much to prevent, it cannot absolutely assure immunity from accidental explosion.

A slight flaw in a fuse bridge, which, it should be remembered, is usually only $\frac{1}{1000}$ in. in diameter, might easily cause a rise of temperature to ignition point with considerably less current than is normally required to fire the fuse.

Every detonator under test should be suspended freely in an iron pipe about 3 in. in diameter, or in a special iron box arranged for the purpose.

The further precaution of placing other detonators where they cannot possibly be struck by fragments from a fuse accidentally exploded should also be observed.

The Author has exploded disconnected detonators at a distance of $4\frac{1}{2}$ in. from the one purposely fired.

56.—Explain the Faults to which Mechanical Exploders are Liable, and Show how they may be Remedied?

Testing Mechanical Exploders.

The troubles that may from time to time occur with mechanically-operated exploders are usually trivial and such as can be seen on casual examination. Displaced or worn-out brushes in the case of dynamo exploders, loosened terminals, oxidised contacts and similar ruptures, complete or partial, in the electrical circuit are the principal causes of failure. Magneto-exploders may fail through loss of magnetism or breakdown of insulation in the armature coils. The latter may arise through imperfect design, or it may result from the storage of the exploder in a damp place.

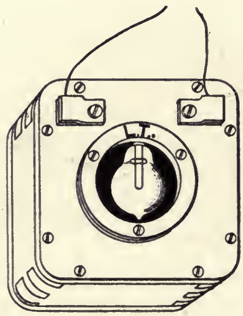

Fig. 54.—Exploder Tester.

Messrs. John Davis & Son have introduced a simple form of exploder tester, which fulfils all the requirements of an instrument intended to be used by shot-firers. Fig. 54 almost conveys in itself sufficient information to indicate the manner of its application. It consists of a special incandescent lamp, carried in a suitable lamp-holder, and enclosed in a small case which has on one side a stout glass disc about 2 in. diameter, mounted in a bezil. Wires from the lamp are connected respectively with two brass-plate terminals arranged to make wedge-contact with a pair of wires from the exploder that is to be tested. To make a test, the exploder wires are wedged on the indicator terminals, the firing-key is pressed and the handle rotated at normal speed. Satisfactory working condition is shown by incandescence of the lamp, as seen through the disc in front of the instrument. These testers may be used to ascertain the strength of either continuous or alternating current, high-tension or low-tension generators; but, it need scarcely be observed, the same instrument is not applicable to every machine. To ensure reliability, the makers should be advised as to the kind of exploder with which it is intended to be used.

The tester supplied by the Roburite Company consists of a small polished board fitted with terminals and a resistance coil in the style shown in Fig. 55.

The machine to be tested is connected to the terminals at one end of the board, a fuse (not a *detonator* fuse) is joined to the terminals at the opposite end and the exploder operated as for firing a charge. If it is in good order the fuse bursts. The resistance coil should have a resistance equal to that of the usual firing line and fuse plus a margin to allow for bad joints and similar possible sources of loss of power.

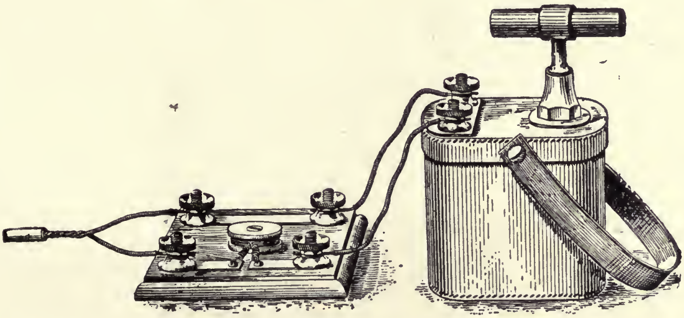

Fig. 55.—Resistance Coil for Testing Condition of L.T. Exploders.

57.—How is the Condition of a Dry Battery or Accumulator Shot-firing Set Ascertained?

Dry-cell exploders, and, it might be added, all other chemical generators, are best tested by means of an accurately-calibrated low-reading voltmeter. Knowing that the normal E.M.F. of a single secondary cell is 2 volts and that of a dry cell 1·5 volts, the simple application of a pair of wires from the terminals of the cell to those of the instrument gives visible indication, by movement of the voltmeter needle over a scale, as to the exact pressure available.

An accumulator cell showing less than 1·85 volts requires re-charging. A dry cell giving a voltmeter deflection below 1 volt should be discarded.

When testing a number of cells coupled together in series, the pointer should indicate a pressure equal to that of a single cell multiplied by the number of cells in the group.

A very compact form of cell tester for accumulators or dry cells is represented in Fig. 56. This instrument measures $5\frac{3}{8}$ in. by 5 in. by 3 in. It has a perfectly even scale and is provided with a knife-edged pointer and mirror. The usual range is 3 volts on either side of a central zero. If required it can be fitted with a simple attachment showing the actual internal resistance of the cell under working conditions.

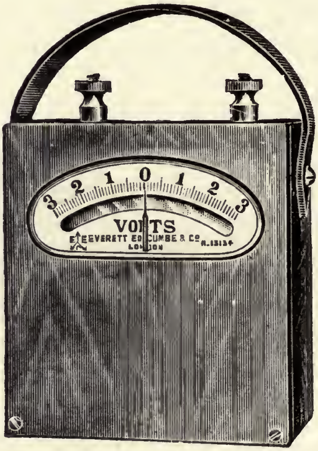

FIG. 56.

58.—Describe Methods of Testing Shot-firing "Cables" for (a) Continuity of Circuit, (b) Leakage between Wires, (c) Leakage between Wire and Earth.

Testing Firing Lines.

The cables used for the purpose of placing a safe distance between the operator and the explosive charge are liable to be injured by falling débris, rough handling, lying in water and in other ways. Sometimes a wire may break inside the insulation, either as the result of a blow or more probably by the frequent straightening out of kinks.

Again, the insulation may be abraded, in which case there would be leakage to earth, supposing the faulty spot to lie on moist ground.

A test would be made :—

(*a*) To ascertain the continuity of the circuit.

(*b*) To determine the amount of leakage either between the two wires or from each wire to earth.

Continuity of Circuit.

Continuity of circuit can be tested by joining two ends of the firing line together and touching the other extremities on the terminals of a combined galvanometer and dry battery, as shown in Fig. 57. If the circuit is good the fact is indicated by deflection of the galvanometer needle. Absence of movement, or a very irregular one, shows that the wire is broken, or partly so.

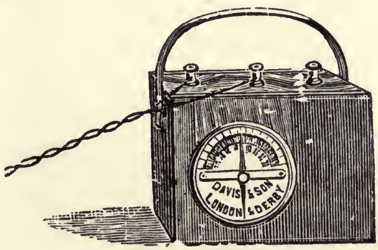

Fig. 57.

Leakage between Wires.

If two ends of a firing line are joined to the terminals of a testing set as above and the opposite ends are left free from contact with each other and with the ground, deflection of the galvanometer needle indicates leakage between the wires. The leakage would, however, need to be considerable for it to be proved by the use of a dry-battery tester.

It is advisable wherever proper insulation testing sets are obtainable to make use of them for determining the condition of firing lines. A galvanometer does not *measure* either pressure or current, it merely serves to indicate the presence or absence of current flow.

Leakage between Wire and Earth.

To detect leakage between a main and earth join one end of each cable to the tester leaving the opposite extremity of one free and connecting the other to "earth." Deflection of the pointer indicates leakage *on the wire which has not been purposely "earthed"* (for explanation *see* p. 76). By repeating the test with the positions of free and "earthed" wires reversed the condition of the other one can be similarly ascertained.

CHAPTER III.

PRACTICAL APPLICATIONS.

59.—What Points require to be Specially Noted in the Execution of the following Series of Operations:—

(1) Drilling the Shot-Hole; (2) Charging and Stemming; (3) Connecting the Firing Line; (4) Exploding the Charge?

Drilling the Shot-Hole.

The depth and direction of shot holes, as also the weight of the charge, are governed by the nature of the material to be dislodged, the position of bedding and jointing planes, faults, fast and loose ends, &c., and are best determined by practical experience. The diameter of holes should be uniform and in general not larger than will pass the explosive without applying undue force. In sets of drills there is often a difference of diameter between the several "bits" after they have been much used. This variation, if unobserved, may be the means of causing a cartridge to stick fast at the place where the ridge occurs; in which event the operator will more often than not use force to drive it to the end of the hole. In the case of explosives containing nitro-glycerine (*v.* p. 4) this action is very liable to cause disaster, owing to the explosion of particles of exuded nitro-glycerine by friction against the sides of the hole.

And even where gunpowder (*v.* p. 8) is used sufficient heat may be developed by the contact of particles of grit or stone to produce ignition.

It is, therefore, important that drills should not be used when they become so worn as to fail of giving easy clearance to the charge.

A test gauge might be carried and applied to the points of each "bit" before drilling a hole, as a means of guarding against the danger referred to. Holes should be well scraped out and, if damp, dried as far as may be practicable. The maximum rending effect, apart from the influence of other conditions, is obtained when the charge exactly fits the shot hole.

The maximum effect is, however, not always desirable, since it is often necessary to make use of an explosive which is more violent in its action than the nature of the material to be blasted in itself requires. Gunpowder, it is well known, exerts a force comparable with that of a wedge, while dynamite explosions—to follow out the analogy—are more closely allied to powerful hammer blows. Permitted explosives (*v.* p. 9) as a whole may be said to lie in a graduated range of effect between gunpowder and dynamite.

And as the Permitted class tends to be used almost exclusively for coal mining, it is often found advantageous to reduce in some way the tendency towards local pulverisation.

Many practical pitmen claim that less damage is done to coal by using cartridges of considerably smaller diameter than the shot hole, thus allowing a portion of the initial explosive energy to be lost by expansion. Fig. 58 shows the application of a Monobel cartridge $\frac{3}{4}$ in. diameter in a $1\frac{1}{2}$ in. hole.

Preparing and Stemming the Charge.

The manner of attaching a fuse or detonator to a charge varies in different localities. It is probable that many instances of defective ignition occur through neglect to bring a fuse or detonator into sufficiently effective contact with the primer cartridge. Many explosives are in appearance not unlike sawdust, and a detonator, if carelessly inserted, may only touch a few loose particles of the mixture, or may, indeed, become entirely detached during the operation of stemming.

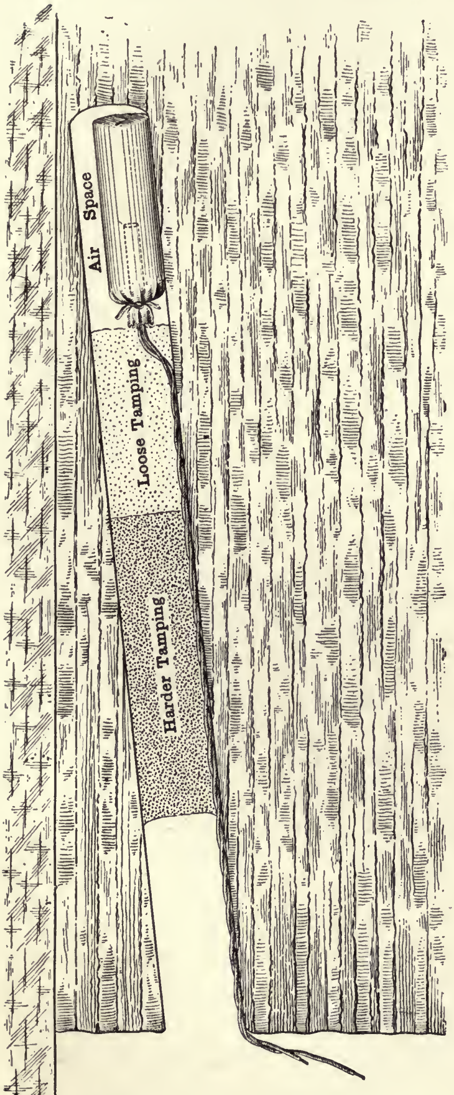

Fig. 58.

S.F.G.

To ensure complete detonation of the whole charge the detonator should not be smaller than the size specified by the makers of the explosive, and *it should be entirely buried in and brought into the closest possible contact with the explosive.*

The Lancashire Explosives Co. recognise the importance of this point by sending out a special peg (Fig. 59) to be used for boring detonator holes in cartridges. It will be observed that the peg is chisel-shaped instead of being pointed. This enables the shotfirer to bore a hole the exact size of a detonator, and with a square end; whereas a pointed stick may leave an air space in the charge beyond the detonator.

The foregoing remarks will have made it evident that a detonator must be securely attached to its cartridge, and not inserted in such a manner that there can be the slightest possible risk of its withdrawal during the subsequent operation of stemming. In some explosives special provision is made for the prevention of mishaps of this kind. Tonite, being a solid compressed explosive, has a suitable opening for the insertion of a detonator left during the moulding process.

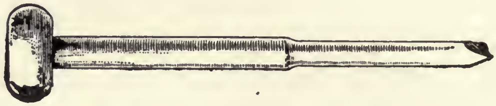

Fig. 59.

The outer waterproofed covering is fitted round its neck with a brass binding wire, the free ends of which can be twisted round the conductors for the security of the detonator, after the manner shown in Fig. 60 (A).

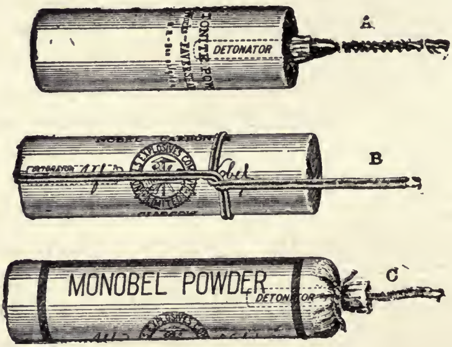

Fig. 60.

Where devices of this kind are not provided, a detonator may be put in at the rear end of a cartridge, the wires turned back, and secured by a half hitch as indicated in Fig. 60(B).

An alternative method is provided in Fig. 60(C), which illustrates a detonator pushed into a cartridge and secured round the neck by string.

Explosives of the metallic-cased variety, such as Ammonite, are primed by cutting off the neck end of the casing and boring a hole sufficiently deep to ensure the whole of the detonator being buried in the explosive, as shown in Fig. 61.

In wet holes extra care must be taken to ensure a tight joint by using a little tar or grease round the neck of the cartridge.

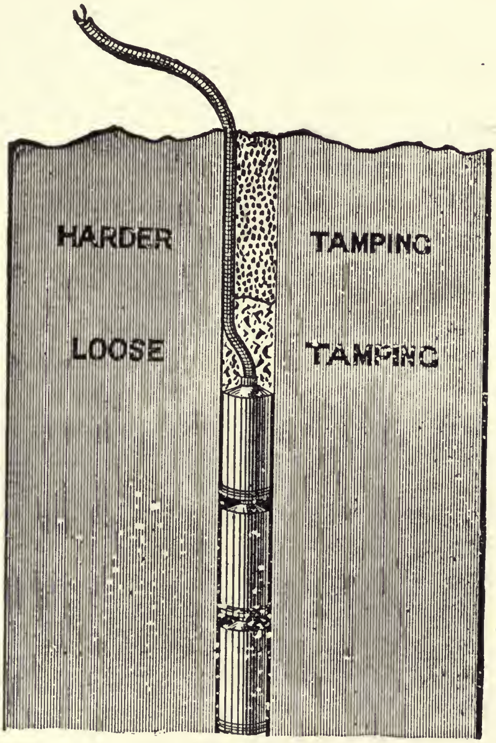

Fig. 61.

When ready for charging, cartridges to the required weight are *gently pressed*, one at a time, to the back of a borehole with a wooden rammer. In ramming charges into a shot-hole there must always be some danger, and it cannot be too strongly urged that this operation should be carried out with the least possible exercise of force.

Great care should be taken to avoid jamming or "bunching," *i.e.*, tying two or more cartridges together, or otherwise inserting several at the same time. H.M. Inspectors of Explosives drew attention some years ago to the desirability of using cartridge of a suitable diameter for the bore-hole, and the necessity for inserting only one cartridge therein at a time. "It is reasonable to conjecture," says a report relative to certain accidents due to the neglect of these precautions, "that either the rammer got jammed between the cartridges and the sides of the hole, or that one or both of the cartridges stuck across the borehole, and that force had to be used either to withdraw the wooden rammer or to press down the cartridges, and this force, acting on (probably) a thin smearing of the explosive on the hard rock, caused the explosion.

Danger of "Bunching" Cartridges.

"The obvious remedy (in addition to the rigorous avoidance of anything like forcible handling of the rammer) is to use cartridges which are a *reasonably and moderately easy fit for the borehole, and only to push home one cartridge at a time.*"

The primer cartridge, viz., that containing the detonator, is inserted last of all, and the charge is then stemmed, lightly at first with about 6 in. of loose stemming, and afterwards harder (*see* Figs. 58 and 61).

Stemming or Tamping.

This consists in filling up a shot-hole above the charge of explosives, in order to oppose a resistance to the gaseous products of explosion in the direction of the borehole. Failure to carry this out properly results in the ejection of the stemming. In other words, it produces that wasteful and, in fiery or dusty mines, most dangerous effect—a blown out shot.

It will be noticed in the section on Safety Regulations that certain materials are conditionally prohibited for stemming. Certain specified tools, moreover, are required, particulars of which will be found in the same section (*v.* p. 169).

The most generally used stemming consists of plastic clay, which is first rolled into short plugs and rammed gently after insertion in the hole. When firing in stone the borings made by the drill are frequently employed. The French Committee on Explosives, after conducting experiments with sand and clay stemmings, leaned towards the conclusion that sand gave better results in practice. The sand stemming was considered to oppose greater resistance than plastic substances to blowing out, which, of course, is a factor of considerable importance in the case of fiery and dusty mines.

Capt. Desborough, of the Home Office Testing Station, has carried out experiments to show the economic gain of thoroughly tamping charges, and presented the results of his experience in the Annual Report of H M. Inspectors of Explosives for the year 1907. Equal charges, according to this report, were fired at the ballistic pendulum, both stemmed and unstemmed, with the same weight of charge—viz., 100 grammes —and the following average results were obtained :—

Explosive.	Swing of pendulum in inches.		Decrease in effect.
	Stemmed.	Unstemmed.	
Blasting gelatine ...	3·73	2·54	31·9 per cent.
Gelignite......	3·05	2·09	31·6 ,,
Gun-cotton	2·79	2·42	13·3 ,,

It will be noted that the relative loss of effect is more than twice as great with the gelatinised explosives than with gun-cotton. In an earlier series of experiments with an ammonium nitrate explosive it was found that the loss of effect due to the absence of tamping was even greater than was the case with the gelatinised explosives above mentioned.

In the course of investigations as to the minimum quantity of stemming necessary to produce the complete explosion of the explosive it was ascertained that, after a certain length of stemming (between two and three times the length of the charge) had been well rammed home, the addition of a further quantity caused no perceptible augmentation to the swing. This, Capt. Desborough explains, was most probably due to the fact that the explosive was already sufficiently confined to ensure the production of the maximum energy which was capable of being generated by the active chemical changes of the explosion, and that consequently any added stemming would not increase the muzzle energy.

As, however, the requisite minimum length of stemming must vary according to the nature of the material employed for the purpose, and probably also according to the nature of the explosive, *the only safe rule to follow in practice is to use as much stemming as possible and to make sure that it is well rammed.*

Having regard to the probability, now recognised, that an explosive forms different decomposition products, and therefore different explosion phenomena, when fired under varying conditions of pressure, the operations of shot firers in mines, with regard to the quantity of explosive used in a charge and the sufficiency of stemming, should receive more attention than has hitherto been considered necessary.

60.—What Precautions are Necessary when Ramming or Stemming a Charge?

H.M. Inspectors of Explosives have frequently observed in their Reports that in ramming charges into a borehole there must always be some danger, and it cannot be too strongly urged that the operation should be carried out with the least possible exercise of force. The best method of preventing this class of accident is to ensure that the men are not allowed to use drills which have become much worn, and also that the diameter of the cartridge is such as to give good clearance even with a slightly worn drill. The important thing to ensure is that the cartridge shall not stick in the borehole, as if it does the miner is quite certain to use sufficient force to get it to the bottom of the hole.

After the care which should be devoted to the drills, the other points which require attention are (i.) to avoid bunching the cartridges (*i.e.*, tying two or three together or otherwise inserting several at the same time), (ii.) the use of wooden rammers, (iii.) the thorough softening of all nitroglycerine explosives before use.

Even with all the above precautions, however, the use of undue force may always cause an accident. A general impression seems to exist that, at any rate in the case of gunpowder, no amount of ill-treatment with wooden, or even copper tools, can possibly lead to danger; whereas, as a matter of fact, sufficient heat to ignite gunpowder may without much difficulty be produced by the contact of two particles of flint or other hard substances without the intervention of iron or steel—the absence of which, therefore, merely *reduces* the risk.

It should be known also that there is for every explosive a certain density which is most favourable to its complete detonation. A charge should therefore be stemmed as nearly as possible in the condition in which it is sent out by the makers.

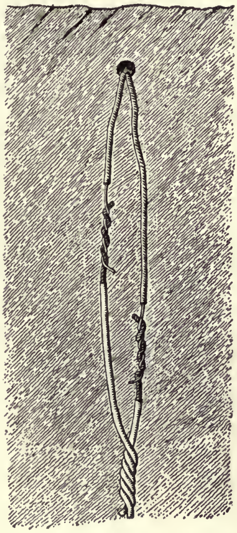

Fig. 62.—Showing Joints.

Connecting the Firing Line.

After stemming, one fuse wire should be made shorter by two or three inches than the other one, so that the two joints made with the firing line may not be accidentally pulled together and thus cause a miss-fire.

All wire ends should be scraped bright before splicing or connecting to terminals. Omission to adopt this recommendation may result in so great an increase in the external resistance of the circuit as to materially reduce the firing capacity of the exploder, especially if the latter is of dry cell type.

Making Joints.

Joints should be made in wires by laying the cleaned extremities across each other, scissor fashion, and twisting the free ends over right and left four or five times. The manner of twisting and arranging the position of joints relative to each other are shown in Fig. 62.

Another joint, partly twisted in the correct way, is seen in Fig. 51(B); the example A in the same sketch serves to illustrate a looped joint, which is incorrect and ineffective as a means of conducting electric current (*v.* also p. 91). When the joints have been satisfactorily made the cable or firing line must be paid out to a place of safety (*v.* Rules in Chapter V.). The proper method of coiling and uncoiling cables has been already described.*

The firing line must always be paid out FROM *the shot-hole* TO *the place of safety*, where the exploder (unless it is a belt or pocket battery) has been previously deposited.

Having reached the desired shelter, the shot-firer carries into effect such inspections and precautions as the special rules under which he may be working (*v.* Chapter V.) and his own judgment demand ; then he connects the free extremities of the firing line to the exploder, and fires the charge.

NOTE.—If the shot-firer has occasion to leave the firing line, even momentarily, after having paid it out, he must take the exploder with him.

After a shot has been fired, the shot-firer should immediately disconnect both ends of the cable from the exploder, free it from any chance débris which may have fallen upon it, and coil it up.

This instruction should be followed even when a miss-fire has occurred.

61.—How may a Charge Miss Fire?

Miss-Fire Shots.

Where the practice of electric shot-firing is well established, failures of any kind only happen at rare intervals, and even then they are more likely to have been brought about by some lapse on the part of a man new to the duties than to any defect in materials. Difficulties often arise where electric shot-firing is introduced for the first time owing to the use of ill-assorted apparatus. The low-tension system may, for example, be adopted. A dry cell is obtained, along with 30 yds. or 40 yds. of shot-firing wire. Perhaps a thin single strand wire, say No. 22 S W.G., is used. After firing comparatively

* Chap. II, Part II., p. 35.

few shots further ignition becomes impossible, and the fact is frequently lost sight of that the greater part of the energy of the cell has been used up in overcoming the resistance of the line. (This point is further developed in the following pages.)

It is often noticed too, that, under the conditions already referred to, there are frequent complaints as to the number of bad "caps," that is to say, electric fuses or detonators. Electric fuses are, however, now so well made that as a general rule the fault may be safely assumed to be elsewhere.

In the report for 1905, of the Chief Inspector of Mines for the Midland district (comprising the counties of Bedford, Berks, Buckingham, Cambridge, Derby, Hertford, Huntingdon, Leicester, Middlesex, Northampton, Nottingham, Oxford, Rutland and Warwick), Mr. A. H. Stokes gives the total number of shots fired (in his district) as 2,305,591, or 162,904 more than in the year 1902. The percentage of miss-fire shots are: High tension 0·42 per cent., low tension 0·23 per cent., and gunpowder 0·25 per cent.

FIG. 63.
DIAGRAM OF LOW-TENSION FUSE WITH SEVERED BRIDGE.

The averge percentage of miss-fired electrical shots is thus 0·3 per cent., it being assumed that the gunpowder shots are fired by means of tape fuse.

And only a small fraction of even this small percentage of failures will, as a rule, be traceable to defects in fuses or explosives. In all but a very few the failure may be traced to one or other of the following causes:—

In the exploder, the electrical pressure may have fallen below that intensity necessary to overcome the resistance of the circuit.

The firing cable may offer too great resistance, owing to (*a*) badly-made joints or (*b*) defective insulation, arising either from mechanical injury, absorption of moisture or use of too fine gauge wires.

In a low-tension fuse, (*a*) the bridge may be severed, as in Fig. 63; (*b*) the bridge may be shunted, as in Fig. 53 (p. 72); (*c*) there may be insufficient priming, or the latter may be damp, in which case the bridge would incandesce without causing ignition; and (*d*) if fuses are tested before firing a defective bridge may then give way without firing.

In high-tension fuses, the wires in the fuse heads (*a*) may make contact with each other, thus passing a current without decomposing the priming; (*b*) they may not make sufficiently good contact with the priming, in which case the electrical resistance is too high for an ordinary high-tension exploder.

In either variety, if a charge be left overnight in a wet hole, the insulation of the fuse wires may be destroyed. Consequently, none but guttapercha covered wires should be placed in wet holes, unless the shot is to be fired immediately after having been stemmed.

Accidents of manipulation, in tamping and connecting up, may result in missed shots, thus :—

Whilst tamping, (*a*) the insulation of the fuse wires may be abraded and short-circuited. This is especially liable to occur in anthracite mines, where the particles of coal are sharp edged and hard, and may easily cut the wires during the operation of stemming. On testing such a circuit in situ, by means of, say, a Holden firing apparatus or rack-bar or Manet exploder, the indicator would show continuity and lead one to suppose that the fuse was in good order.

(*b*) A wire may have been inserted in the shot-hole kinked; then, upon tamping, the strain put upon the wires by an inexperienced operator causes the weakened point to straighten out and give way inside the insulation.

(*c*) The wires may be partly carried into the hole by an advance stroke of the tamping rod; they are pulled out again forcibly, thus bringing about result (*a*) or (*b*).

(*d*) Manipulative accident (*c*) may result in the detonator being withdrawn from the cartridge, or the fuse from the detonator. (This may be entirely obviated by inserting the detonator in the cartridge, then doubling back the wires alongside the primer and making a half hitch with them round the same. The detonator end of the primer leads into the shot hole. (*See* B, Fig. 60, p. 82).

(*e*) Splicing fuse wires in a shot-hole. (A miner will have caps with, say, 36 in. wires. He has occasion to bore a 48 in. hole, and so he twists pieces of old fuse wire on to the new, lays the joints side by side, and proceeds with his stemming. The fireman comes along, applies his exploder, and "wonders why it won't go off"!)

In connecting the fuse and the exploder, (*a*) the joints between the fuse and the firing line may be dirty or covered with tallow grease. (They should be rubbed bright between thumb and finger, with a pinch of coal or shale dust, before splicing.)

(*b*) The manner of jointing may be mechanically but not electrically good. (*See* pp. 67 and 87.)

(*c*) The joints, though properly made, may have been inadvertently brought into contact with each other, whilst reeling off cable.

(*d*) The firing line may have been kinked and afterwards forcibly straightened out, thus breaking a wire.

(*e*) The exploder ends of the firing line may require cleaning; as may also the binding terminals or contact studs on the exploder itself.

62.—What is "Double Detonation"?

Double detonation may occur when a shot partly misses or hangs fire—a form, in fact, of delayed ignition. A damp detonator or badly mixed explosive are the two principal causes of double detonation.

The insertion of a fuse in place of a detonator, or the use of a weak detonator may fail to detonate, but succeed in igniting the charge. Then, according to Sarrau's theory, the pressure developed by the gases would be sufficient to explode the remainder of the explosive. (*See* also Question 63, following.)

63.—Can an Electrically-Ignited Shot Hang Fire?

In view of the fact that four pit sinkers were recently reported to have been injured at a Sunderland colliery owing to the unexpected explosion of a blasting charge, it cannot be too well known that electrically ignited charges can and do at times hang fire. Under the Quarries Act "If a shot has apparently missed fire, no person shall be allowed to go near it until after the lapse of half an hour, except where electricity has been used," and in coal mines an electrical miss-fire is exempted from the regulation as to the fixing of caution boards or fences.

The North Staffordshire Special Rule provides that if a shot misses fire, no person shall return to it "until after the lapse of at least one hour; if, however, the shots are fired by electricity, the authorised shot-firer or competent person may return immediately, after disconnecting the cable of the battery and taking the battery with him." A similar rule is in force in Shropshire and Cannock Chase. These rules rather favour the idea that electrically ignited shots do not hang fire and may thus in some measure prove a source of danger.

It is not unusual for one in a group of simultaneously-fired shots to miss, and consequently there is always an element of danger in group-firing. Probably a nearer approximation to perfect safety would lie in the use of electrically ignited time fuses, though it must also be admitted that the use of a suitable detonator would go a long way towards ensuring the simultaneous ignition of any number of shots.

Hang-fire, or retarded ignition, may occur in the electric detonator or it may occur in the explosive. A damp detonator might readily hang fire.

It is well known that a shot will sometimes explode after prolonged turning of the exploder handle, whereas in general less than half a turn will suffice. The retardation might be caused by increased resistance in the circuit through broken wires, bad joints, or grease or dirt on spring contacts and terminals, permitting the passage of only just sufficient electrical energy to warm the fuse bridge. The latter has then to be kept heated during several seconds before the temperature rises to the point of ignition of the priming. The same effect would be produced if the exploder were under-powered, owing, for instance, to loss of magnetism. Or delayed ignition might be caused by defects in the fuse, such as badly mixed, damp, or insufficient priming, or by a wet charge.

Capt. Desborough (Annual Report for 1905, p. 137) states that he had electrical hang-fires when firing experimental shots with three different ammonium nitrate explosives, that of greatest duration involving an interval of about 50 seconds between the explosion of the detonator and the explosion of the charge. With all these explosives he subsequently had several miss-fires, and in each case, when the charge was extracted, he found that the detonator had fired, but had failed to explode the charge. The difficulty was overcome when a stronger detonator was employed. In this connection Capt. Desborough mentions that a cartridge of carbonite was found to be burning in a shot-hole in a colliery in South Wales. This was by no means the first instance of the kind, and the caused seemed to lie in the use of a faulty or insufficiently powerful detonator.

The Annual Report of H.M. Inspectors of Explosives for 1906 also records three cases in which a hang-fire has occurred with electric firing. In one of these cases two attempts were made to fire a shot electrically (high tension); the cable was then disconnected from the detonator leads and tested. It was found to be all right. The shot then exploded. There is practically no doubt, says the report, that this was a case of hang-fire. The time elapsing between the disconnection of the cable and the explosion of the charge was about five minutes.

After the introduction into France of safety explosives, several accidents happened at St. Etienne Collieries and were made the subject of an investigation and a report by Mr. L. Volf. The following notes from a translation of Mr. Volf's report, which appeared in the *Transactions* of the Institution of Mining Engineers, show that the accidents were attributed to the phenomenon of double detonation, which is another phase of retarded ignition or hang-fire.

It was assumed that in a borehole charged with cartridges, only the first was exploded by the detonator, and that the others became ignited after an interval of a few seconds or minutes. The following accident proved this: Three holes, each filled with $3\frac{1}{2}$ oz. (100 grammes) of *grisounite-couche*, were bored in the coal, and ignited by 0·052 oz. (1½ grammes) detonators and three fuses.

Three distinct reports were heard, and, as the workmen were going away, a shot which was still smoking exploded and injured one of them ; it appeared to have exploded twice. The theory deduced was that the decomposition of a blasting charge is not the result of a single chemical reaction, but depends on the pressure to which the products are exposed during such reaction.

Dynamite, guncotton, nitrate of ammonia, and other blasting materials containing nitrates, decompose gradually in the air, and give out nitric oxide, but if they are ignited in a closed space they instantly decompose, without forming a trace of nitric oxide. The first slow process changes immediately into the second if the free evolution of gas be hindered and the pressure raised. The reaction produced by a detonator is the same as that by ignition in a closed space at high pressure. Both are so rapid that the whole of the charge is at once converted into gas. But if the ignition be defective, the charge may ignite and burn instead of exploding ; it is then said to "cook," and gives off nitric oxide. The explosive power of a charge also varies with its composition, and depends, in grisounite upon the small quantity of nitro-napthalin that it contains.

If the charge begins to burn, the increasing pressure caused by the gases given off may produce an explosion and ignite the cartridges one after the other.

At the Karwin Mine (Austria) 20 holes were bored and fired in three series. The first and second series having been fired (by means of a Tirmann low-tension dynamo exploder) from a distance of 260 ft., a loud report was heard, and the workman was proceeding to fire the remaining holes when a second report ensued, about 15 seconds after the first. It was impossible to tell which of the shots had produced the first, and which the second report, but all had gone off. The boreholes were about 4 ft. deep, and each contained, besides the firing cartridge, five or six others.

On another occasion six shots were fired at a distance of about 130 ft., and there was an interval of a minute or more between the two explosions.

Twenty-five experiments were then made to discover the reason for the retarded ignitions. In two, the dynamite did not explode at all, and in several it was only partly burnt, while three miss-fires were caused by the machine.—(From an article by the Author in the "Colliery Guardian.")

64.—Show how the Practical Efficiency of a Blasting Circuit is governed by its Electrical Resistance.

Successful electric shot-firing can only be attained by giving due recognition to the electrical laws governing this application.

Suppose, to illustrate a way in which an exploder may fail to do the work expected of it, a dry cell, say $2\frac{1}{2}$ in. in diameter and 7 in. in length, with an internal resistance of 0·7 ohm, has been selected to fire Nobel low-tension fuses through a 90 ft. twin wire of No. 20 S.W.G. It can be seen, almost at a glance, that the apparatus is foredoomed to failure, for the total resistance of the circuit ($Ri + Rl + Rf$) exceeds 3 ohms, and, since about 0·6 ampere current is required to fully incandesce a fuse-bridge, it follows, by Ohm's Law (electromotive force = current × resistance), that the electromotive force (1·5) is barely sufficient to overcome the resistance of the circuit. If, on the other hand, a cell of lower internal resistance, say a C size Obach with Ri value 0·25 ohm (*see* Table IV., p. 54), is selected, together with a firing-line containing more copper, say 3/22 S.W.G., this apparently trifling modification makes all the difference between failure and success.

The total resistance in the latter example is as follows :—

	Ohms.
Ri (internal resistance of cell)	0·25
Rl (resistance of firing-line—that is, of 180 ft. of 3/22 S.W.G. cable)	0·79
Rf (resistance of fuse-bridge)..	0·75
Total resistance	1·79

On taking the product of $1·79 \times 0·6$ (fusing current) it is found that the electromotive force required to drive that current through the circuit is less than the electromotive force available at the terminals of the battery; hence this set may be expected to perform its work in an efficient manner.

It need scarcely be said, however, that in order to obtain maximum economy, allowance must be made to compensate for various sources of increased resistance. In the first place, there is the internal resistance of the cell to be considered. This increases gradually so long as the cell lasts; rapidly, indeed, if the exploder is heavily worked. And, as increased internal resistance means less effective electromotive force at the terminals of the cell, this alone may render the cell incapable of firing a fuse.

(It should be remembered that all types of exploders have a definite internal resistance, and this requires to be taken into account when using very small machines. In the larger sizes the margin of power is so great that in practice the internal resistance can be ignored.)

The firing line, again, may be expected to receive frequent cuts from flying pieces of rock or coal, thus necessitating splices or joints that may or may not add seriously to the resistance; according as they are properly or improperly made.

The best method of making a joint in small wires or strands has been explained (*see* p. 66). An injured cable should, of course, be sent out of the mine for repairs as soon as possible, but it is frequently necessary to make temporary splices in order that the round of a district may be completed without delay.

Another source of failure against which it has been found needful to instruct blasters is that of making two splices opposite each other. If two joints have to be made, it is better to cut off a foot or so of one wire on each piece.

Then, on bringing the long and short wires of opposite cables together and splicing, the joints will be separated from each other by insulation.

It may further be noted that if the insulation of a firing-line becomes saturated with water, the resistance between the two wires may be so much reduced as to provide an easier path for the current than through the bridge of the fuse. The latter would then, as a matter of course, fail to go off. Other analogous sources of failure in the firing line will doubtless readily suggest themselves.

Passing now to the fuses, it is found that they are of somewhat widely varying resistance; from which it follows that a battery and line admirably adapted for the ignition of one make of fuse may be utterly useless with another pattern.

Low-tension fuse bridges are variously made of platinum, platinum-silver, and iridio-platinum, and range in electrical resistance from about 0·3 ohm to 1·65 ohms. Hence, when, as is often the case, the resistance of the fuse is unknown, it is desirable that an ample margin of power in the exploder should always be available.

65.—How do Permitted Explosives of the Gunpowder class compare with other Permitted Explosives as Coal Getters?

Some recent experiments, which were carried out for the Bobbinite Committee, go to prove the generally accepted belief that gunpowder and its allies are still the best explosives for producing strong coals, not only because these non-detonants on the whole *get* the coal with less production of small, but because coal so got is not shattered or cracked, and suffers the least amount of disintegration in conveyance from the coal face to the consumer.

Table VIII. shows the general result of the experiments, which were made in the four seams of widely varying nature. These were the "Stanley Main" seam at the Don Pedro Pit, Whitwood Collieries, Normanton, in South Yorkshire; the "Deep Hard" seam at Moorgreen Colliery, Eastwood, in Nottinghamshire; the Bydelog" or "Black Vein" seam at the Victoria Colliery, Ebbw Vale, in Monmouthshire; and the "Nine Feet" or "Big Vein" seam at Ystradgynlais Colliery in the Swansea Coal Field.

Table VIII.—*Some Results of Experiments as to the comparative merits of Explosives.*

—	Bobbinite.		Carbonite.		Ammonite.		Saxonite.	
	Large.	Small.	Large.	Small.	Large.	Small.	Large.	Small.
Don Pedro Pit, Whitwood Colliery	Tons cwt. 41 19½ (77·7 p.c.)	Tons cwt. 12 0½ (22·3 p.c.)	Tons cwt. 40 6½ (77·7 p.c.)	Tons. cwt 11 11 (22·3 p.c.)	Tons cwt. 38 10¼ (74·3 p.c.)	Tons cwt. 13 6 (25·7 p.c.)	Tons cwt. 40 9¾ (74·1 p.c.)	Tons cwt. 14 3¼ (25·9 p.c.)
Victoria Colliery, Ebbw Vale	73 10 (65·0 p.c.)	39 11 (35·0 p.c.)	70 5 (64·9 p.c.)	37 19 (35·1 p.c.	82 10 (64·0 p.c.)	46 8 (36·0 p.c.)	93 1 (62·4 p.c.)	54 17 (37·6 p.c.)
Moor Green Colliery, Eastwood.	38 7 (78·6 p.c.)	10 9¼ (21·4 p.c.)	38 7¾ (75·8 p.c.)	12 4½ (24·2 p.c.)	37 13¾ (73·6 p.c.)	13 9¾ (26·4 p.c.)	37 1 (73·7 p.c.)	13 3½ (26·3 p.c.)
Ystradgynlais	41 8 (81·3 p.c.)	9 10 (18·7 p.c.)	26 9 (75·0 p.c.)	8 16 (25·0 p.c.)	— —	— —	29 9 (76·4 p.c.)	9 2 (23·6 p.c.)
Average percentages: Large	73·2	...	71·3	...	68·4	...	68·5	...
Small	...	26·8	...	28·7	...	31·6	...	31·5

N.B.—The dead small was not taken separately, but was lumped in with small, the screens being 1 in. to 1½ in.

BLASTING IN PIT SHAFTS AND STONE HEADINGS.

66.—What are the Advantages of Electric Firing in Shaft Sinkings and Headings?

Ignition by electric current ought to be the only permissible means of firing blasting charges in shaft sinking and tunnelling operations.

For rock blasting and all tunnelling work, shot-firing by electricity is acknowledged to be the most economical besides being safer than any other system. Moreover, in such places as shafts and tunnels, where ventilation may be defective, it is usual under the old system for workmen to wait perhaps half an hour or more after each blast to allow smoke and fumes to clear away, and when several blasts are made daily much valuable time is thereby lost.

Smaller charges will lift more rock when fired simultaneously by electricity than would greater ones if the holes were fired independently with tape safety fuse. It has also been proved that the same amount of work can be accomplished with a less number of holes where electricity is employed than would be required if the charges were fired singly with tape fuse.

In case of a miss-fire the advantage of electric firing is more evident, as, if the holes are not simultaneously exploded, there is but little possibility of a smouldering fuse lying dormant and exploding when unexpected,* and, consequently, less danger in approaching the charge to ascertain the cause of miss-fire.

Given a code of rules, as a protection against thoughtlessness and ignorance of the risks involved, it should, by the use of electrical methods, and assuming that adequate provision is made for the enforced observance of the rules, be almost impossible for any accident to occur.

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* *See* "Hangfires," p. 91.

67.—State the Advantages and Disadvantages of Series and Parallel Firing; Show how to calculate the Resistance of the Circuit for each System; and give the Resistance of High and Low-Tension Fuses.

Fuses for simultaneous ignition may be joined in series, or in parallel, as shown in Fig. 66.

In the series system, wherein line and fuse wires are all coupled consecutively, the total external resistance of the circuit is equal to the sum of the separate resistances (external resistance $= Rl + (Rf \times N)$); where Rl is resistance of line, Rf resistance of one fuse, and N the number of fuses in series.

In the parallel system the circuit may be compared to a ladder, the line forming the ladder sides and each detonator fuse a stave.

The total external resistance in this system is $Rl + (Rf \div N)$. It is thus seen that the resistance varies inversely as the number of fuses.

The resistance of H.T. fuses is very variable, and may be anything from 50 ohms upwards.

The resistance of a L.T. fuse, on the other hand, is usually about 0·7 ohm, and rarely exceeds 1·5 ohms.

As a general rule H.T. fuses are fired in parallel and L.T. fuses in series.

When firing in parallel, as is usual in ignition from lighting mains, a bad fuse simply misses fire while the rest explode. In a series circuit, on the other hand, a defective fuse usually causes the entire blast to miss fire, though the system has the advantage that a fault can be easily located.

If a great number of fuses have to be fired, say, more than 50, the best way is to arrange them in groups of about 20 in series, and join the groups in parallel. In this way the number that can be fired is limited only by the current available and the carrying capacity of the mains.

68.—How are Shot-Holes arranged in a modern Shaft Sinking?

In the Sherwood Colliery sinking (Mansfield, England), all the shot-holes were set out systematically from a centre line:—

Six inner sumper holes, 6 ft. deep and 2 in. in diameter, were drilled in a circle of 4 ft. radius; and 16 outer sumper holes, 6 ft. deep and 2 in. in diameter, were drilled in a circle of about 9 ft. radius.

The whole of these inner and outer sumper holes were fired together by electricity, and the débris cleared away.

Then 24 side holes, 6 ft. deep and 1¼ in. in diameter, were drilled at a radius of 11 ft. These side holes were all fired together, and left the shaft-side quite clean, and practically no dressing was done by the pick.

The average rate of sinking only through this (magnesian limestone) was 22½ ft. per week.

In the softer coal-measures, five sumper holes, 7 ft. deep and 2 in. in diameter, were drilled in a circle of 4½ ft. radius; and 10 outer sumper holes, 7 ft. deep and 2 in. in diameter, were drilled in a circle of 10 ft. radius.

The remaining 16 inches of rock were dressed off by hand when the ground was soft; and where hard rocks were encountered, side holes 6½ ft. deep and 1¼ in. in diameter were drilled as in the limestone. The finished diameter of the shaft was 20 ft. (J. W. Fryar, *Trans.* I.M.E., Vol. XXVI., 1903-4.)

69.—What Shot-firing Precautions should be taken when Sinking through Frozen Ground?

In sinking by the freezing process at Dawdon Colliery explosives were used to blast through the limestone, the natural hardness of which was intensified by the frost. Great care was required, in placing the shot-holes and regulating the quantity of explosive used, to prevent any breakage of the freezing tubes surrounding the shaft and so cause a leakage of brine, which might damage the ice-wall.

The following shot-firing regulations were adopted:—

(*a*) Black compressed powder must be used for all shots.

(*b*) Sumping holes must not be more than 50 in. deep. Not more than 12 in. of powder, including the primer, may be used in any hole. The shots must be fired by electricity, and not more than three holes may be fired at one time.

(*c*) Connect or side holes must not be placed nearer than 12 in. to the side of the shaft, and not more than 40 in. deep. Not more than 6 in. of powder, including the primer, may be used in any hole. The holes must be drilled at an angle of 17 to 20 degrees towards the centre of the shaft. Not more than one shot may be fired at one time.

The preceding regulations necessitated the drilling of a large number of shot-holes, and also entailed a great amount of shearing-back of rock to dress the shaft-sides straight down.

The shot-holes were kept from freezing either by using a solution of 6 per cent. of caustic soda or 10 per cent. of washing soda. (E. Seymour Wood, *Trans.* I.M.E., Vol. XXXII., p. 566.)

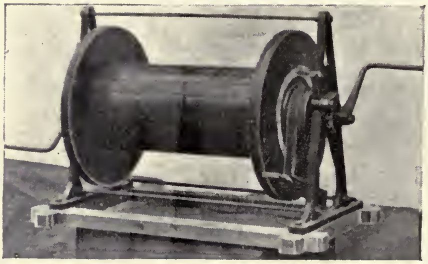

Fig. 64.

70.—How is Electrical Connection made between the Charges at the Bottom of a Shaft and the Exploder at the Surface?

Electrical connection between the bottom of a shaft and the surface may be made by suspending bare wires on insulators from the shaft mouthing to a point a few yards above the sump or shaft bottom. The lower end of the cable being specially liable to injury by flying débris, a separate length of twin flexible cable is used to make connection between the shaft wires and the charges to be fired. This method necessitates joint making as the sinking of the shaft progresses. It is, therefore, often considered preferable to carry a length of twin insulated wire upon a drum situated at the surface of the mine. The cable, of which there should be sufficient to allow of damaged ends being frequently cut off, is lowered down the shaft whenever shots are required to be fired, and wound up after having served its purpose.

A useful type of drum, as made for this purpose by Messrs. John Davis & Son, is shown in Fig. 64. It consists of a wooden cylinder, having galvanised iron or zinc flanges, the whole being carried between two cast-iron uprights rigidly connected by tie bars. On one flange there are two brass terminals insulated therefrom by ebonite bushes. The inside ends of the firing line are securely attached to the terminal nuts inside the flange and the cable is then reeled on to the drum. In operation, the cable is lowered down the shaft by means of the cranked handle, a weight being hung on the end to facilitate its descent. The shots are connected together in series, the free ends joined to the firing line and the men withdrawn from the shaft. A flexible cable is then joined from the exploder terminals to those on the drum flange and the charges are fired. This loose surface connection provides an additional safeguard against accidents.

71.—Give an Example from Recent Practice of the Methods employed in driving a Stone Drift.

The following data are useful as showing the actual methods employed in driving a cross measure drift from the low main to the Maudlin seam, at Houghton Colliery, and are quoted from a Paper on the subject by Mr. Norman Nisbet in the *Proceedings* of the National Association of Colliery Managers for 1907 :—

"The thickness of the strata between the two seams was 10 fathoms, consisting, in ascending order, of 1 fathom of blue metal, 6 fathoms of strong seamy post, and 3 fathoms of a strong blue metal intermixed with ironstone nodules varying in diameter from 2 in. to 2 ft.

"The drift was let to contractors, the conditions of contract being as follows: (1) Drift shall be driven 8 ft. wide by 7 ft. in height throughout; (2) and shall be driven at a uniform rising gradient of 2½ in. to the yard; (3) Drift shall be driven by mark, and shall be straight, the centre line to be in the same relative position throughout the whole length of the drift; (4) No shot shall be fired within 1 ft. of the roof or sides, and all loose stone affected by shots shall be dressed back by hand; (5) Price to include cost of explosives, which will be supplied at the rate of 4½d. per lb.; (6) Contractors shall fire all shots in drift and shall set sufficient timber to keep themselves safe; (7) All stones to be filled into tubs; (8) The appearance of anything except solid stone in the face of the drift shall immediately terminate the contract; (9) The drift shall be driven continuously from 10 p.m. Sunday till 12 noon on the succeeding Saturday; (10) Contractors will be supplied with power drill and gear—all drills and picks being sharpened by the company; (11) A price per yard for driving the drift in accordance with all the above conditions, the drift to be driven in a proper and workmanlike manner, &c.

"The drift was let to five men at the price of 35s. per yard plus the then existing percentage, which was 27½ per cent. Refuge holes, 5 ft. by 5 ft. by 3 ft., were made every 20 yds. and were let complete at 32s. 6d. each. The drift was driven the full distance of 158 yds. in 19 weeks, or 4¾ months, the average yardage driven per week being 8·3, or 16·6 yds. per fortnight. The maximum yardage in any one fortnight was 20 yds. of drift and one refuge hole. The average number of shifts worked per fortnight per contractor was 16, and the average wage over the whole time of driving was—not including fillers, who were paid a fixed wage—12s. 6d. per shift of eight hours. Out of the five men in the drift, three worked the drill and prepared and fired the holes, while the two fillers filled the stones made in the night shift, and were, as mentioned above, paid a fixed wage at the rate of 5s. per shift.

"The method of working the drift was similar to that usually employed with hand drilling, with the exception that all holes were drilled by machine, the face being sometimes fired right across and sometimes worked sump and back-end, according as the conditions suggested. Sumping, covering and flanking holes were employed and placed according to the judgment of the contractors, who took advantage of the bedding and cleavage planes of the stone in placing their holes. As a rule, 13 to 16 holes, of from 5 ft. to 6 ft. each in length, were drilled for each round. This work was sometimes accomplished in four hours under favourable conditions, or at the rate of 24 lineal ft. of hole per hour, including all time spent in setting up and taking down drill, while as many as two complete rounds of holes were occasionally drilled, fired and the stones filled away in the 24 hours, clearing 10 ft. of drift. In two actual instances the times occupied in drilling two holes under different conditions were as follows:—

1st hole in blue metal with ironstone nodules 6 ft., drilled in 16·5 min.
2nd hole in mild blue metal was drilled 6 ft.

	h. m.	
Started drilling	11 57	1 min.
1st drill up	11 58	
Started 2nd drill	11 58·5	1½ "
2nd drill up	12 0	
Started 3rd drill	12 0·75	1¼ "
3rd drill up	12 2	
Started 4th drill	12 3·5	1½ "
4th drill up	12 5	
Total time ...	8 min.	

"The drill used was an Ingersoll-Sergeant auxiliary valve rock-drill of the D 24 type, diameter of drills 2½ in. to 2 in. Drills used in soft ground were of chisel section, while in hard ground, where ironstone nodules were encountered, drills with a rose or star bit were used. The drills, of best tool steel were tempered in water from a peacock blue at the cutting edge through to a dull red in the body. Three drills were necessary to drill a 6 ft. hole. Air pipes of 3 in. diameter were laid up the drift from a 12 in. air main at the bottom, the flexible hose for connection with the drill being 1 in. in diameter. The drill, running 430 strokes per minute, is supposed to consume 100 to 110 cubic ft. of free air per minute. The explosive used was Saxonite, with high-tension detonators. The quantity used was 2,271 lb., which cost £96. 10s. 4d., equal to 12s. 2·6d. per yard of drift; 2,076 detonators, costing £10 15s. 9d., were used, making the total cost for explosive and detonators £107. 6s. 1d., equal to 13s. 7d. per yard. The average quantity of explosive per hole was 1·09 lb. The greatest quantity of explosive used in one fortnight was 350 lb. with 260 detonators, for 14 yds. of drift, equal to 25 lb. per yard, or 1·35 lb. per shot, at a cost of 21s. 3d. per yard for explosive, or a cost of 23s. 2d. for both explosive and detonators."

Wires for shot-firing in headings, &c., should either be paid out from a coil each time they are wanted or, if the heading is

FIG. 65.—EXAMPLE OF SIMULTANEOUS BLASTING IN SERIES.

a long one, bare iron wires may be carried on insulators attached to the timbering or side of the road. In the latter case a twin flexible insulated wire is used in the head-end to make connection between the fuse wires and the permanent mains.

72.—Give an Illustration of Simultaneous Series Blasting in a Quarry and indicate the Advantages of this Method.

In Quarry work it is generally agreed that a substantial saving of explosives is to be obtained by simultaneous firing, since each shot helps its neighbour and there is no binding except at the extreme end of the line of holes. This advantage is further increased in certain kinds of work by using explosives of different strengths in different parts of the same hole. By the exercise of individual judgment and experience in this and similar ways the quality and quantity of stone obtained may be considerably increased.

A method of quarrying by simultaneous blasting in series is shown in Fig. 65.

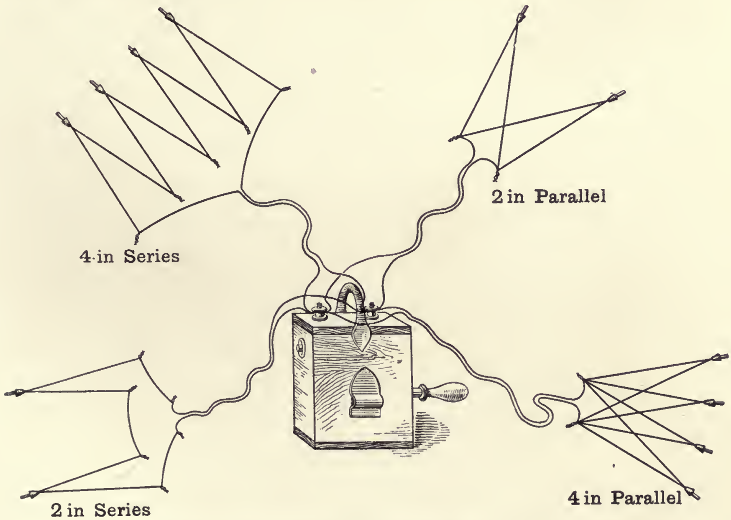

Fig. 66.—Method of Connecting Fuses for Group Firing.

73.—Give an Illustration showing Series and Parallel Methods of Connecting Fuses for Simultaneous Firing.

Various methods of connecting fuses for group firing in series and parallel are shown in Fig. 66 above.

CHAPTER IV.

BLASTING ACCIDENTS.

PART I.

RISKS IMMEDIATELY CAUSED BY THE EXPLOSIVE.

The risks following the use of explosives in mines may be broadly divided into :—

(1) Those immediately caused by the explosive, and

(2) Those resulting from the ignition by the explosive of an inflammable atmosphere.

The former arise, for the most part, owing to want of knowledge and skill on the part of those engaged in blasting operations, as will appear in the subsequent development of their causes. It might be said, too, that the latter, the risks classed under (2), are often caused in the same way, though as perhaps a higher order of knowledge is requisite for the prevention of these risks there may be a little more excuse for the person by whom they are brought about.

It has been asserted in evidence given before the Coal Mines Commission, now sitting, that 90 per cent., if not the whole, of those who are acting as "competent shot-firers" have no theoretical knowledge at all as to explosives. Those who know most of the type of men who are generally employed as shot-firers will be the first to agree that the statement is one of fact rather than a mere personal expression of opinion, and it is greatly to be desired that men so occupied should be legally compelled to acquire that competence for which they either do not understand the necessity or have not sufficient sense of responsibility to voluntarily obtain.

The questions and answers in this chapter contain accounts of many blasting accidents of commonly recurring type and, indicating as they do the principal causes and means of prevention, will, it is hoped, help to lessen the frequency of these unfortunate occurrences.

74.—How may the various Accidents caused by Explosives be broadly Classified?

Accidents caused by Explosives. The accidents caused by explosives may for convenience be grouped under the following sub-heads :—

(*a*) Accidents in Handling Explosives.

(*b*) Accidents whilst Stemming and Preparing to Fire.

(*c*) Accidents when Firing.

(*d*) Accidents after Firing or attempting to Fire.

75.—Describe the Main Sources of Accidents which occur in handling Explosives.

(*a*) *Accidents in Handling Explosives.*—A fruitful cause of accidents in countries subject to low atmospheric temperature is the neglect on the part of users to soften nitro-glycerine explosives so as to render them plastic and fit for use. All nitro-glycerine explosives, as pointed out in Messrs. Nobel's handsomely prepared "Book of High Explosives," become congealed during cold weather, and this may occur even at a temperature as high as 45°F., and *this congealing may exist without any apparent alteration in the soft and plastic outward appearance of the cartridges.*

The following circular, issued by the Nobel's Company, to which H.M. Inspectors of Explosives have drawn public attention, will be of interest in this connection :—

IMPORTANT NOTICE.

Directions for the use of Explosives in Cold Weather.

All cartridges before blasting should be heated in warming pans. Specially designed warming pans should alone be used for this purpose (Messrs. Nobel's warming pan is shown in Fig. 67), and in them the cartridges can be kept in a proper usable condition for several hours in the coldest weather.

Fig. 67.—Nobel's Warming Pan.

On no account expose cartridges to the direct heat of fire, or place them on a hot stove or warm piece of metal, or on a steampipe.

Do not attempt to heat them by these or any other irregular means, or *accidents* thereby will *inevitably occur.*

There should be *no fire,* &c., in the hut or apartment in which the thawing is conducted.

One cartridge at a time should be *gently pressed,* not forced, to the back of the borehole, and great care should be taken to *avoid jamming or "bunching."*

It may be added that explosives which have never been allowed to become hard by solidification of the nitro-glycerine do not show so much tendency to freeze as those which have been frozen once and subsequently thawed.

Knowledge of the fact that since 1871 80 persons have been killed and 123 wounded while attempting to thaw explosives in ovens, on hot plates, over fires and in other similar ways should induce those in authority to see that their workpeople are properly and frequently informed as to the most approved methods of handling dangerous material, and the shot-firers themselves to beware of that familiarity which breeds contempt.

76.—Has it been observed that Accidents with Nitro-glycerine Explosives occur more frequently at one time of the year than at another?

Yes. These accidents almost entirely occur during the cold months of the year. The number of accidents has been found to steadily increase from November till February and then decrease again in May.

77.—What do you consider the safest method of thawing Frozen Explosives?

To thaw them in a warming pan of the kind supplied by the explosives manufacturers. A proper warming pan consists essentially of a double vessel similar to that used for the purpose of cooking oatmeal porridge. The explosive is put into the inner compartment and hot water poured into the outer. The pan must not be heated in any other way. An illustration of one of these pans is shown in Fig. 67, on previous page.

78.—Describe the Russbach Pot for softening or thawing Dynamite.

The Russbach pot consists of two cylindrical vessels, fitting one into the other, with double walls, lined with non-conducting material, and provided with a double-lined cover. To maintain an average temperature in the pots of, say, 122°F. for 10 hours, the inner vessel is plunged for 15 or 20 minutes into water kept on the boil, dried, placed inside the other vessel, and the cover replaced. A number of experiments were made about five years ago to measure the temperature of the walls of the empty vessel, and of its interior. After placing it for 15 minutes in boiling water, the temperature of the walls when withdrawn was 107·6°F., and of the interior 105·8°F. At the end of five hours they were respectively 102°F. and 87·8°F.; and at the end of 10 hours, 62·6°F. and 53·6°F. The temperature of the outer air was very cold. The vessel tested was of 305 cubic in. capacity, and if previously heated as described, 8 to 9 lb. of dynamite at a time could be softened in three or four hours, and $5\frac{1}{2}$ lb. during the next four hours.

79.—What other Accidents than those caused by Frozen Material may occur in handling Explosives.

Another kind of accident in handling is reported in the 1905 Report of H.M. Inspectors of Explosives, from which many of the examples following are also taken. A contractor, having prepared the charge and fixed the detonator, is said to have attempted to make a water-tight joint with the fuse by cutting off a piece of the explosive (Blasting Gelatine) and applying a lighted match to melt it. When the cartridge caught fire the deceased attempted to extinguish it by grasping it in his hand, whereupon it exploded.

Fifty-seven accidents are reported to have been caused during 1905 by explosives being ignited by a naked flame or spark in the course of blasting operations, and in every case but two gunpowder was the explosive involved.

Three persons were killed and 63 injured by these accidents, which were, in many cases, due to nonconformity with the usual regulation enjoining the removal of the candle or lamp from the cap before preparing a charge.

Numerous accidents also occur in connection with the insertion of a detonator in a charge, and also in the practice of "socketing," which consists in the use of small charges for enlarging the end of a borehole, to enable a powder charge to be concentrated at the back of the hole.

Others have arisen owing to want of knowledge as to the extremely sensitive nature and violent properties of fulminate of mercury, which is the essential component of a detonator.

There is an instance recorded of an official shot-firer in a mine who withdrew the electric fuse from a detonator cap and then proceeded to extract "the stuff in the end of the tube" by the aid of a pin. The "stuff" of course exploded, and the official lost one eye and three fingers.

Another accident occurred in the following manner at a colliery where electric shot-firing had recently been introduced: A number of underground officials were together in their "cabin," engaged in writing their reports. One of them was testing electric detonators through a dry cell and galvanometer circuit. The latter instrument had three terminals, one common, the other two attached respectively to low and high-resistance coils. A certain "cap," just tested, gave no deflection on the galvanometer needle, and was therefore inferred to be a bad one. An onlooker essayed to repeat the test, and, assuming that the detonator really was faulty, applied, as he thought, the same test as before. Unfortunately for him he completed the circuit through the low instead of the high-resistance galvanometer coils and the detonator "went off." The man lost two fingers. Another operator tested a detonator through a low-resistance galvanometer, and, cautious in his way, used a dry cell supposed to be almost exhausted.

He, too, neglected the important precaution of placing the detonator in an iron tube or otherwise out of harm's way before testing, and, as its "bridge" chanced to be somewhat weaker than usual, it exploded, and a piece of the copper capsule became embedded in his eye.

Eleven accidents of this character occurred in 1905. In three of these cases it seems probable that the injured persons were fully aware of the dangerous nature of the article, and had only their own folly to blame for their injuries.

In two cases there is no reason to suppose that the injured persons had any idea of the danger they incurred, while in six cases it may be assumed, from the fact that a light was applied, that the injured person was aware that they are explosive, but was probably unaware that they were dangerously so.

80.—Detail some further Detonator Accidents.

There were 22 detonator accidents in 1906. The following examples will, it is hoped, serve to indicate the extreme sensitiveness of detonators and the great risk involved in unskilful handling.

1. A boy received from a schoolfellow a detonator which, with others, had been stolen from a box at a pit in the neighbourhood of Linlithgow. He put it on the fire and it exploded, causing him to lose several fingers of his right hand.

At Glasgow a boy was picking at a detonator with a pin when it exploded and blew off two fingers. At Hett, Durham, a man found a loose electric detonator in a box and was, he said, in the act of replacing it, at the same time folding up the wire, when it exploded, seriously injuring his right hand. He was probably pulling at the wires.

At a clay pit in Flint a detonator exploded, from some unexplained cause, in a man's hand, and at a quarry in Derbyshire a man was cutting off the end of a detonator to make a ferrule for his pipe when it exploded.

At a colliery in Lanarkshire a man was extracting the detonator from the primer of a missed shot, when it exploded, and at Easter Jaw Colliery, Stirling, a detonator exploded when a piece of fuse was being inserted in it.

A boy picked up a detonator in Glasgow and was merely scraping at the composition with the butt end of a match when it exploded, and so injured his hand that it had to be amputated.

At a Warwickshire colliery a man was picking dirt out of a detonator when it exploded, and at a quarry in Gloucestershire a detonator exploded in a man's pocket while he was drilling a hole.

81.—Is it not specially risky to work with Naked Lights in proximity to Explosives?

Yes, such procedure argues the possession of a defective intelligence. No less than 70 accidents were caused in 1906 by explosives being ignited by a naked flame or spark in the course of blasting operations, gunpowder being the explosive involved in every case but two.

Seventy-six persons were injured by these accidents, which were, in many cases, due to nonconformity with the usual regulations enjoining the removal of the candle or lamp from the cap before preparing a charge.

82.—State how Accidents have occurred during recent years whilst stemming and preparing to Fire.

That any considerable number of accidents are liable to occur whilst tamping charges is a fact which might easily escape observation were it not for the evidence annually assembled in official publications. Yet in 1905 39 such accidents caused seven deaths and injury to 43 persons (*see* Chap. III., p. 86, for precautionary measures). Another type of accident is that resulting from the use of electrical means of ignition. It is generally caused either by thoughtlessness or want of knowledge regarding the exploding apparatus and the effects liable to be produced by it.

Several cases of premature ignition have been caused by the use of a defectively insulated shot-firing cable. The latter is necessarily damaged in daily use by falling fragments of stone or coal. Both wires of a twin cable may lose their insulation at the same point and come in contact, thus short-circuiting the line. A charge having failed to explode, the line, if suspected, is examined, the exploder, say of the dry battery type, being meanwhile left in circuit. The "short" is found and removed, and the shot exploded in doing so.

Instances of this kind might be related to an almost indefinite extent. Eight accidents in electric firing occurred in 1905, resulting in three deaths and injury to five persons.

No less than five of these accidents might have been avoided by a more systematic method of carrying out the operation. *It should be an invariable rule that the wires are never to be connected to the exploder when anyone is at the shot-hole, and that the man who last leaves the working place is the only one to be allowed to connect the wires to the exploder.*

Accidents which have occurred through the practice of "bunching" Cartridges :—

1. At a Durham quarry. One person killed and three injured.

The deceased was ramming a final charge of three cartridges into a shot-hole with a wooden rammer. The hole had been chambered by a previous shot, and had been recharged with 23 lb. of gelatine dynamite. A proper warming pan was provided, but had not been used. The cause of the accident was probably the jamming of the three "bunched" cartridges, which may have been frozen.

2. At a quarry in Fife. Three persons injured.

The three injured men were charging a 14 ft. hole, using a wooden rammer. The charge exploded, injuring one of them severely. The men were "bunching" the cartridges by lying them in bundles of three or four, a practice which is likely to cause them to stick in the hole and so create undue friction in charging.

3. At a colliery in Kinross. One person killed and one injured.

Three cartridges had been bunched together, and whilst being rammed home they stuck in the bore-hole. The men endeavoured to force them home with a wooden rammer. The gelignite was probably frozen.

Accidents through Boring into Unexploded Charges :—

Figs. 68 and 69 illustrate two fatal accidents which occurred in 1900 in Lancashire collieries.

In the first (Fig. 68), a collier drilled a hole in the roof for a ripping shot ; a fireman charged the hole with 8 oz. of amvis, and made several attempts to fire by electric battery, without success. He then told the two stallmen of the failure to fire the shot and that they must drill another hole, taking care to have it 8 or 9 in. from the old one, and not to drill into the old hole.

As the second hole was being drilled the charge exploded, killing one man and seriously injuring another. Examination

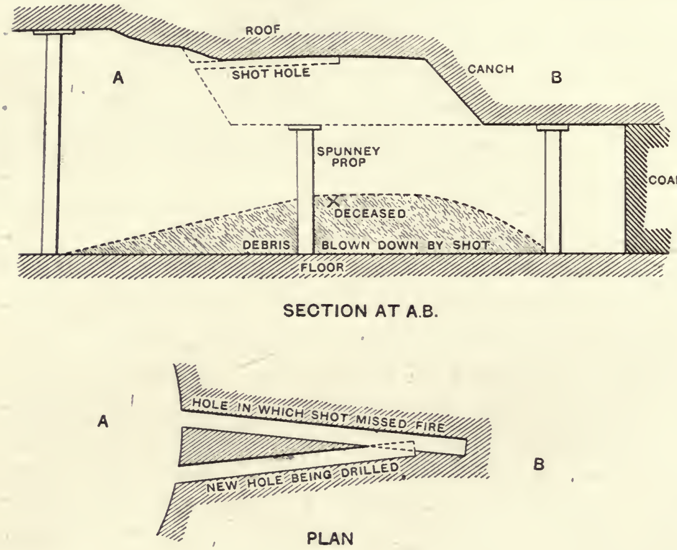

Fig. 68.

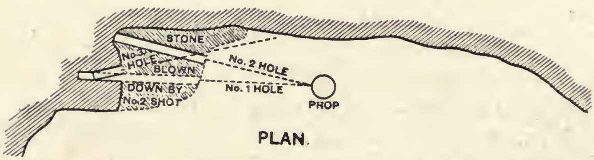

Fig. 69.—Fatal Accident by Explosives at Linnyshaw Colliery, May 31, 1900.

proved that the second hole was only $5\frac{1}{2}$ in. from the first hole, that the hole was so directed that it entered the old hole; the drill had removed some of the clay stemming, two or three inches of explosive, and then struck the detonator.

Mr. Gerrard, H.M.I.M., from whose Home Office Report these particulars are obtained, suggested to the fireman that he might chalk on the roof the direction of the old hole, chalk mark the position of the new hole, and also its direction. This valuable precaution is now included in the Lancashire Special Rules.

In the second accident (illustrated in Fig. 69), a chargeman had failed to fire a shot—it missed fire—at 5 a.m., he then left the mine. At the top of the pit he told the ongoing chargeman to try again to fire the shot. Again there was a failure, and a hole was then stamped out for a new shot, $5\frac{1}{2}$ in. from the old one. The new shot was fired at 8:30 a.m. and brought down a quantity of stone. At 10 a.m. a third hole was started; whilst being drilled there was an explosion, and two men received serious injury. Examination proved that the third hole had been started by the side of the socket left of the first hole, which contained the detonator and the unexploded charge. It was obvious that the men had, without careful examination, concluded that the second shot had exploded the charge of the first shot; the third hole had been started after very slight examination of the face.

(*c*) *Accidents when Firing.*—Accidents have frequently happened where men, either from ignorance of the fact that a shot was being fired or from want of judgment, exposed themselves to the flying débris. Rigid adherence to a suitable code of rules should be the means adopted for the prevention of this class of casualty.

Following are records of a number of accidents belonging to this class: —

1. *Through not taking Proper Cover.*—At a mine in Durham deceased fired a shot by electricity when standing 23 yards from the shot-hole in the direct line of fire. He was struck by a stone. A small refuge hole was available close by.

A shot-firer was struck by débris from a shot in a Derbyshire mine through using so short a cable that he could not take proper cover. A minimum length of cable is now specified in the Explosives in Coal Mines Order (*see* 2 (*e*), p. 173).

Some eight years ago an accident of an almost incredible nature happened in a north country colliery, and is instanced as evidence of the necessity for extreme caution in those engaged in shot-firing. In Fig. 70 will be seen a plan and sections through a heading or tunnel driven in the rock. Two men, father and son, having connected the line wire with a charge, in the head end, placed themselves for safety behind the second ventilation door as shown. The young man, standing with his back to the door, fired the shot and, according to the father's statement, the door opened at the moment he heard the sound of the explosion and his son rolled over dead.

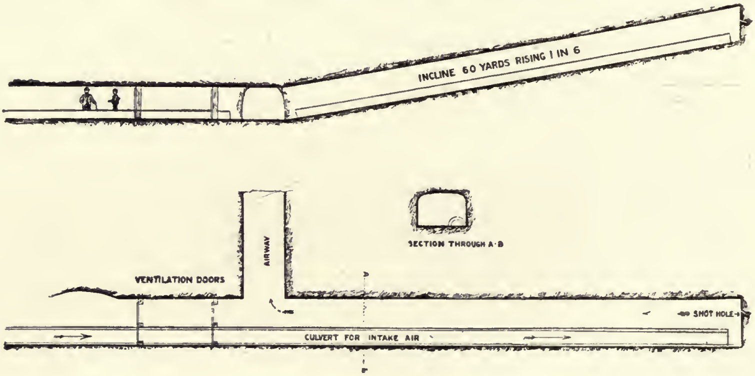

Fig. 70.

2. *Through neglect or omission to see that all Persons are in safe positions before completing the Firing Circuit.*—Two men were recently killed at different Durham collieries. Each was connecting the cable to the detonator leads, when the shot-firer, thinking the man had taken cover, exploded the charge.

At a colliery in Northumberland a shot missed fire, and on testing the cable it was found to be defective. The shot-firer cut off a portion of the cable and sent the hewer to short-circuit the further end of the cable (for the purpose of a re-test). Through some misunderstanding, the latter connected it up with the detonator leads, and on the shot-firer attempting to make the test the charge exploded, killing the hewer.

At a Durham colliery, whilst the shot-firer was connecting up the leads, the hewer by mistake turned on the current, causing the shot to explode.

At a Staffordshire mine a shot was fired while the cable was being attached, through the use of the battery for testing cable at the same time. One man was killed and another injured.

A shot-firer left the cable from a missed shot attached to his low-tension battery. On coupling the shot wires to the cable the charge exploded and he was killed.

Another accident, the cause of which will strike the reader as being particularly stupid, occurred in a midland colliery.

A shot-firer, having made the connection between the wires connected to the charge and his line, requested another workman to hold the wires apart at the joints, so that in paying off cable no short-circuit would be produced through an inadvertent pull. Having paid out sufficient length to place himself in a safe position, he immediately fired the shot, forgetful of the fact that his comrade was holding the wires at the shot-hole. It is difficult to say which of the two men most deserved the inevitable punishment.

3. *Through contact with Electric Signal Wires.*—An unexpected fatality occurred some years ago in a stone drift branching at right angles off a main haulage road. In the head end, distant, perhaps, 80 or 100 ft., a shot-firer joined the fuse wires to his firing line, and proceeded to pay out the latter towards the main road at the same time that the workmen were engaged in removing their tools from the working face. On the arrival of the official at the junction of the roads the portion of firing line remaining uncoiled was passed over a set of bare iron electric signal wires. In this act either the two free ends of the cable or possibly a bare end of one and an uninsulated place in the other in some way completed the circuit through the signalling battery, and as a consequence the charge exploded, causing the death of one of the workmen remaining in the vicinity of the shot.

Another accident, the cause of which was traced to the use of signalling wires, occurred at the Worsley Mesnes Colliery, with fatal results to two workmen. The circumstances (*vide* Report of the Inspector of Mines for the Liverpool District, 1904) were extraordinary.

It appeared that three drill holes were prepared at the face of a steep tunnel, and one of the deceased, who was the appointed shot-firer, came there, bringing his firing battery with him. This he left at the top of the tunnel, and going down, proceeded to charge and stem the three holes, and having completed this work he was heard to say "Which shall I fire first?" Immediately afterwards there was a violent explosion. The evidence given at the inquest made it clear that the shot-lighter used the signalling wires to fire the shot, forgetting, or not appreciating the fact that the wires were attached to or in circuit with an eight-cell battery.

An eight-cell battery (say, 8 or 9 volts) is not normally strong enough to fire a detonator such as was used here, but when a bell is in the circuit and this is rung, there is an induced, or, as it is called in the Report, an "extra breaking" current for an instant giving a spark, as is the case in switching off a motor.

By experimenting with dummy detonators (*i.e.*, electric fuses), Mr. Hall found that it was quite easy to fire the shot by this means; all that was necessary was that the wires should touch each other after being attached to the shot, then instantly the bell rang and the shot went off. In this accident there was a breach of Special Rules in that the deceased shot-lighter did not have his firing battery with him whilst coupling up to the charge.

A third fatality arising out of the use of signal wires for shot-firing occurred at a colliery near Wakefield so recently as April, 1908. Experience cannot teach if men wont learn.

4. *Through misunderstandings between Workmen.*—At least 20 serious accidents have arisen through misunderstanding between a shot-firer and a fellow workmen. A charge for some reason misses fire. One man goes to seek the cause of failure whilst the other waits by the machine. Some signals will be exchanged and misunderstood and the operator starts to work his machine. The shot unexpectedly goes off and an accident is the result. (*See* also 2, p. 120.)

5. *Through the use of defectively Insulated Shot-firing Cable.* —(*See* p. 116.)

6. *Through Delayed Ignition or " Hang Fire."*—(*See* pp. 91-5.)

83.—State how Accidents have occurred after Firing or attempting to Fire.

The majority of the accidents classed under this heading appear to be the result of hang-fires, or cases where miners have returned to the shot-hole believing that the shot had missed fire, or had not been ignited, or that it had fired.

A curious and, it is believed, unexplained accident occurred in the Midland mines inspection district some years ago.

A charge in rock roof failed to fire, and somehow or other passed unnoticed until about a fortnight afterwards, when it is said to have exploded spontaneously and brought down the rock.

A similar occurrence is recorded at a colliery in Glamorgan. A charge which had been much shaken by a neighbouring shot exploded while a workman was attaching the wires. Pressure of the ground was supposed to have caused the explosion.

84.—Has a Charge ever blown through and caused injury in another part of the Mine?

Yes, a charge fired in a vertical hole (in a Cumberland mine) blew through into an upper level and injured a youth standing there.

At a colliery in Northumberland a headways had been deflected from its proper direction, and a hewer was driving a road to connect with it; owing to the deflection he was closer to the headways than he thought, and on firing a shot it blew through, injuring a deputy on the other side.

85.—What special and serious Danger is there in neglecting to look for traces of Explosive in blown-down Coal?

The unexploded charge may find its way into a private house, and cause injury to the occupants and damage to the property.

Two such cases occurred in 1906. In one, a woman put a shovelful of small coals and dross on the fire of her kitchen. A few minutes later a violent explosion occurred in the fireplace, which was destroyed; some damage was done to the house and the woman and her husband were slightly burnt by the coals and hot water. There was evidently some explosive in the coal but it was impossible to ascertain whether this was delivered with the coal or whether it had been dropped by the husband who in his work as a pit brusher would use explosive.

In the other, a violent explosion occurred in the kitchen grate, preceded by a hissing noise. The burning coals were thrown out slightly injuring the four children of the occupier. Undoubtedly the cause was the presence of a blasting explosive in the coal. The manager of the colliery from which the coal had been issued was warned that allowing explosives to be present in coal sent out from a colliery is a punishable offence.

BLASTING ACCIDENTS.

Chapter IV.—PART II.

ACCIDENTS RESULTING FROM THE IGNITION OF INFLAMMABLE ATMOSPHERES.

The Risk of Ignition by Explosives of Inflammable Atmospheres.

86.—How do Gases and Vapours become Explosive?

Gases and vapours in general are not actually explosive except when mixed with air or oxygen, and then only when the mixture is in definite proportions.

Combustible gases and vapours cannot furnish an explosion on ignition unless the air with which they are mixed contains just sufficient oxygen—neither less nor more—for the complete combustion of the vapour present, and this quantity differs for each gas or vapour.

87.—How does the Explosion of a Gas or Vapour proceed?

In the presence of sufficient oxygen the explosion of a gas or vapour proceeds in the following manner :—

Every chemical reaction, even to the smallest, is accompanied by the liberation of heat ; as the chemical reaction progresses it is followed by an increase in the amount of heat, which in turn helps to accelerate the reaction ; and thus the two advance together, both in highly intimate connection and mutually helpful, until the entire mass of the substance has been heated and chemically converted.

When a burning substance—a match for instance—is placed in contact with the extreme outer limit of an explosive mixture of gas and air, the flame of that substance produces ignition at the point of contact, *i.e.*, incites chemical reaction.

This reaction—combustion—proceeds superficially from the outside of the mixture towards the centre, and thereby forms a plane of combustion which divides the gaseous mixture into two parts ; on the one side are the highly heated products of combustion, and on the other is the still unconsumed gas. The dimensions of the two parts vary in proportion as the plane of combustion moves from the consumed to the unconsumed portion.

The velocity at which this plane advances is different for each gaseous mixture, and depends both on the composition of the mixture and on the pressure to which it is subjected, the higher the velocity the greater the rise in temperature, and this latter in turn directly influences the expansion of the gas and the products of combustion, which thereby exert such a strong pressure on their environment (air, walls, &c.) that the opposing medium (the containing vessel, &c.) is ruptured, overturned or burst.

This velocity of propagation of the plane of combustion through explosive mixtures of gas is often extremely rapid, and is comparable to an instantaneous vibration should it occur in a space surrounded by walls but open at the top or on one side; the phenomenon may produce a vacuum there, in consequence of which, and of the action of the external atmospheric pressure on the walls, the latter collapse inwards towards the site of the explosion instead of being thrown down in an outward direction.

88.—Can Gases and Vapours be ignited otherwise than by Flame?

Gases and vapours may be ignited or exploded by heat as well as by flame; in such event, however, the temperature must be comparatively high to produce the effect in question.

Methane explodes by heat at	656–678°C.
Coal Gas ,, ,, ...	647–649°C.
Ethane ,, ,, ...	605–622°C.
Hydrogen ,, ,, ...	555°C.
Acetylene ,, ,, ...	509–515°C.

At these temperatures even pure gases and vapours will explode without air.

89.—Give the Temperatures at which Blasting Materials explode.

The temperatures at which blasting materials explode differ considerably, but are in general lower than for the explosive gases :—

In order to explode	Must be heated to
Kieselguhr, with 50 per cent. of nitro-glycerine ...	180–230°C.
Guncotton, compressed...	186–201°C.
Guncotton, air-dry	137–189°C.
Nitro-glycerine	257°C.
Dynamite	197–200°C.
Blasting gelatine	203–200°C.
Mercury fulminate	175–187°C.
Gunpowder	270–300°C.

90.—Discuss the range of Explosibility of different Gases and Vapours.

A certain minimum quantity of oxygen (air) is necessary to produce an explosion of any gas or vapour by simple contact with flame. This amount differs in every case, and, moreover, the minimum can be exceeded within certain limits up to a maximum, beyond which the mixture again becomes inexplosive.

The range between the minimum and maximum limits differs for each gas and vapour; if small, the explosive range is narrow, and vice versa.

Gases and vapours exhibiting a narrow range of explosibility are far less dangerous than such as have a wide range, owing to the increased margin of possibilities of explosion existing in the latter case.

A particularly antithetical behaviour in this respect is exhibited by acetylene and coal gas respectively. Mixtures of these gases and air become explosive and inexplosive when the percentages of gas in the mixture attain the following limits :—

	Explosive at		Inexplosive at
Coal gas............	8 per cent.	......	23 per cent. and over.
Acetylene	3 ,,	......	82 ,, ,,

It may be well for colliery managers to bear this in mind when considering the desirability of using acetylene safety lamps.

91.—What is a Dust Explosion?

Dust Explosions. It has already been explained that in the case of gas explosions an essential condition is the presence of air or oxygen in a certain proportion.

A gas or vapour may, nevertheless, become explosive without the presence of sufficient (or, indeed, any) air or oxygen should it contain any powdered substance in a state of suspension as fine dust, which latter then partly or wholly takes the place of air or oxygen. The explosion of such a mixture of gas or vapour with air and dust is termed a dust explosion.

92.—What is the chief reason for Dust becoming Inflammable?

The chief reason for this ready inflammability of dust is the occlusion of atmospheric oxygen, or other gases or vapours present, by the minute particles of dust which act like an absorbent sponge. Laden with gas or vapour, these dust particles form a highly inflammable material, which ignites with great rapidity, forming an atmosphere of hydrocarbons and carbon monoxide that furnishes with the remaining air an explosive mixture, which is ignited and exploded by the flame of the burning dust.

93.—What is Occlusion?

Occlusion is the power possessed by solids of absorbing gases. It depends largely on the area of the surface exposed, and varies with the kind of solid and gas.

Thus, one volume of freshly-ignited boxwood charcoal will absorb 90 volumes of ammonia, 10 of oxygen and $1\frac{1}{4}$ of hydrogen. Gases thus occluded are brought into very intimate contact, so that chemical actions will go on which would not take place on mere admixture.

Freshly raised coal is charged with "fire-damp" the composition of which varies in different pits, but in all cases consists for the most part of methane and ethane. The fresh coal, and especially lump coal, continues to give off this gas for some time. During or after the liberation of the methane coal occludes oxygen in quantities which may attain up to 5 per cent. of the weight of the coal in the case of anthracite, and up to 10 per cent. in lignite.

94.—How do Dust Explosions occur?

Dust explosions occur in two stages: The ignition of the dust particles, and the explosion of the resulting and ready-formed gaseous products.

These two phases follow in such rapid succession as to practically form one operation.

Any kind of dust floating in the air can be ignited by the simplest flame, or by electric or other sparks.

The explosion of dust is considerably facilitated by a preliminary warming, or the introduction of a warm gas. Violent motion of the dust particles will also contribute to their explosion; but, on the other hand, shock, percussion or friction unaccompanied by the production of sparks can never cause dust explosions.

95.—What constitutes a dangerous amount of Dust in a Mine?

Experiment has shown that as little as $\frac{1}{3}$ oz. of coal dust per 35 cubic ft. of air will suffice for the production of an explosion, and that it is more a question of fineness of division of the dust than the weight. In addition to fineness of subdivision the per centage of volatile matter in the coal dust has an important influence on its inflammability, and the same also applies to the ease with which these volatile matters are disengaged under the influence of heat.

The Commission appointed by the Societé de l'Industrie Minérale to investigate the causes of coal-dust explosions have pointed out that the great danger of explosion presented by floating coal-dust is evident from the fact that a mixture containing 111 grammes of dust per cubic metre of air (*i.e.*, in the proportion furnishing carbon dioxide on combustion) develops a pressure of 15·5 atmospheres on ignition, as compared with the pressure of 8·9 atmospheres produced by the combustion of an explosive mixture of firedamp and air. Even when the amount of coal-dust is double the above figure, so that carbon monoxide is produced, the pressure generated amounts to 6·7 atmospheres.

96.—What Degree of fineness suffices to render a Coal-dust Explosive?

Dr. Henry H. Payne in a valuable paper on the subject of mine dust as a factor in coal mine explosions, read at the June (1908) meeting of the Coal Mining Institute of America, states that only coal dust which will pass through a No. 100 screen is capable of initial or primary explosion, although secondary explosions may be propagated indefinitely by the larger sizes. Such fine dust, after having been subjected to ordinary atmospheric air for only a few hours, becomes largely decomposed and exists as a bubble of constituent gases whose film is composed of undisintegrated carbon and impurities, which, after combustion are known as ash. Such dust, when suspended in a homogeneous cloud with a moderate air velocity, is susceptible of ignition either through shock, compression, or sufficient heat to inaugurate combustion, and the result will be classified as combustion or explosion, depending upon the volume of dust ignited, its supply of oxygen and the space within which combustion takes place.

97.—At what Temperature does Coal-dust ignite?

Prof. Henri Fayol showed that the temperature of ignition of coal-dust was 356°F. (180°C.) in his work on the spontaneous inflammation of coal.

Dr. Phillips Bedson has described experiments in which he has ignited coal dust heated in an air-bath at a temperature of 284°F. (140°C.)

98.—What quantity of Firedamp will suffice to produce an Inflammable Atmosphere in the presence of Coal-dust?

Prof. Galloway proved experimentally, so long ago as 1876 that " a mixture of firedamp and air in the proportion of one volume of the former to 112 of the latter, becomes inflammable at ordinary pressure and temperature, when charged with fine dry coal-dust, such as that which is to be found on the roadways in dry coalmines."

99.—Is it possible to ignite Coal-dust (without Gas) with a permitted Explosive?

Yes. The explosion which occurred at Wingate Grange Colliery, Wingate on October 14, 1906, originated from flame due to a charge of geloxite being fired on a projecting ledge of rock, probably covered by a mixture of grease and coal-dust. The explosion occurred in a main intake airway, where gas had never been found, and it is generally agreed to have been caused by an ignition of coal-dust and air.

100.—What danger is to be apprehended from failure to clean out Shot-holes bored in Coal?

There is nearly always a certain amount of coal-dust left in holes bored in coal, the amount depending on the hardness of the coal, the inclination of the hole, and the care bestowed on cleaning it out.

According to some tests carried out by the French Commission the conclusions were drawn that the contents of blasting cartridges may become mixed with coal-dust in shot-holes bored in coal and that miss-fires under these conditions may cause the deflagration of the mixture, in which case any firedamp present is certain to be ignited. This danger is also present to a smaller extent in the case of complete detonation, the carbon present increasing the temperature of detonation and producing carbon monoxide, thereby facilitating the ignition of fire damp.

In view of the probability of accidents arising from this cause, the Commission recommend that shot-holes bored in the standing coal should be carefully cleared of dust; that the practice of ramming the cartridges so hard as to break the envelopes and mix the contents with coal dust should be abandoned, and that the size of the detonators should be increased.

101.—How is it that some Explosives are more dangerous to use in the presence of Gas or Dust than others?

It has been conclusively proved that all known explosives, provided they are used in sufficiently large quantities, ignite and explode both pit-gas and coal-dust. It is solely in regard to the limit of the dangerous quantity that they differ from one another. This difference, as M. Bichel points out in "New

Methods of Testing Explosives" (a work which all mining students ought to possess), is, however, considerable. For example, whilst 5 grammes of black powder, blasting gelatine, gelatine dynamite or No. 1 dynamite are sufficient to fire a given mixture of firedamp and coal-dust, the explosion, for example, of 1,000 grammes of carbonite fails to ignite it. The relative safety of different explosives depends on their rate of detonation, length and duration of flame, afterflame ratio (viz., ratio between detonation time and duration of flame beyond it), and temperature.

M. Bichel compares the safest explosives with the least safe as follows :—

Detonation time.	Length of flame.	Duration of flame.	Afterflame ratio.	Temperature.
1 : 4	1 : 5·6	1 : 36	1 : 100	1 : 2

Thus showing that the safest explosive is four times safer than the least safe as to detonation time, 5·6 times safer as to length of flame, 36 times safer as to duration of flame, 100 times safer as to afterflame ratio, and twice as safe as regards temperature.

The flame of all explosives outlasts the time of detonation, but that of the "safe!" explosives does so in a much less degree than in the contrary case.

The range of afterflame therefore appears to be the determining factor in the ignition of firedamp.

In general safety explosives should show a minimum rate of detonation, and a minimum length and duration of flame at a given pressure; none of these should exceed certain limits, as the detrimental effect of one of them cannot be counterbalanced by the others, however favourable.

102.—What is the meaning of the Expression "Charge Limite"?

One of the most important practical points brought out by recent researches is that of fixing a definite maximum charge for every given explosive. It has been proved experimentally that *there is for each explosive a certain maximum weight which will ordinarily fail to ignite an explosive atmosphere.*

M. Victor Watteyn, in a valuable Paper read in Berlin in 1903, termed this maximum weight the *charge limite.*

103.—What is the average annual Loss of Life by Explosions of Firedamp and Coal-dust?

Taking the three decades beginning 1875 and ending 1904—a period during which much deeper mines have been opened, and the number of persons employed underground (in the United Kingdom) increased from 427,017 to 681,683, and the output of coal also increased from 133,306,485 to 232,411,784 statute tons—the average annual loss of life from explosions in the first decade was 256, in the second decade 174, and in the third ending with 1904, 60 lives.

104.—To what is this Improvement attributed?

It is said, on the one hand, that the diminution in loss of life is due mainly to the fact that gunpowder has been prohibited in the majority of coal mines by the Explosives in Coal Mines Orders.

On the other hand the opinion is strongly held that explosives legislation has had little or no effect; the improvement being due to the increased use of safety lamps, more effective ventilation and the more rigid enforcement of the general and special rules relating to the detailed use of explosives.

105.—Would you assume from a period of inactivity that Explosion risks had ceased?

No. From September 3, 1902 until the beginning of 1905 the South Wales coalfield, for example, was remarkably free from explosions, and since May 25, 1901, when seventy-eight men lost their lives at Senghenydd, the loss of life from this cause has been small. Yet in the first half of 1905 there were explosions at Gowerton and Clydach Vale and Wattstown, the latter being the most serious, as measured by loss of life, since the terrible disaster at the Albion Colliery at Cilfynnydd in 1894.

It has been pointed out in an editorial article in the *Colliery Guardian* that these periods of comparative safety are to be taken as having little bearing on the future.

At several intervals in history the South Wales coal trade has enjoyed a similar immunity from accident, the last to be recalled being from 1881 to 1885, and from 1885 to 1890, yet in the latter year, by explosions at Llanerch and Morfa 263 men were killed, and these were followed by explosions at Park Slip, the Great Western Colliery and Cilfynnydd.

106.—Summarise the Result of Investigations to date* on the Influence of Coal Dust as a Factor in Mine Explosions.

The following valuable and comprehensive summary of the conclusions of different authorities on the influence of coal dust as a factor in mine explosions was recently presented to the Coal Mining Institute of America by Dr. Henry M. Payne, Professor of Mining Engineering at the West Virginia University :—

1. Granting that secondary explosions may be propagated indefinitely by the larger sizes, only coal dust which will pass through a No. 100 screen is capable of initial, or primary, explosion.

2. Such dust, after having been subjected to ordinary atmospheric air for only a few hours, becomes largely decomposed, and exists as a bubble of constituent gases, whose film is composed of undisintegrated carbon and impurities, which after combustion are known as ash.

3. Such dust, when suspended in a homogeneous cloud, with a moderate air velocity, is susceptible of ignition either through shock, compression or sufficient heat to inaugurate combustion.

* June, 1908.

4. Such results will be classified as combustion or explosion, depending upon the volume of dust ignited, its supply of oxygen, and the space within which combustion takes place.

5. Where gas alone is ignited, and the mine is free from dust, a "high explosive" effect is obtained, and the explosion may be strictly local, due to the cooling effects of the walls.

6. The chief product of a dust explosion is carbon monoxide, whose expansion under combustion is greater than that of methane, and which receives its continuous supply of oxygen by feeding toward the intake.

7. A dust explosion, while assisted by the intake air, must nevertheless follow those entries or airways furnishing the most material upon which to feed, and when this course follows the return airways, the conversion of the carbon monoxide to carbon dioxide renders the air extinctive, and prohibits further propagation. Evidence of such a condition will be found in the coke splashing, or crusts, formed by the deposit of red hot cinders, carried by the air wave, and testifying to the incomplete combustion.

8. The initial explosion may, and generally does, distil so large an amount of gas that complete combustion is impossible at the site of distillation, and this mass of gas and dust, in varying stages of ignition and combustion, at a temperature greatly in excess of the point of ignition were sufficient oxygen present, will develop into local explosions at irregular intervals, whereever adequate atmospheric oxygen is available, such as at junctions of airways, widened passages for side tracks or cavities where falls of roof rock have occurred, and are frequently called "flame areas."

9. When such an explosion, either primary or secondary, travels toward a dead end of an entry or passage, the compression generated by its expansion and momentum causes an almost incredible rise in temperature, sufficient to distil the various hydrocarbons from even the ribs of the coal itself, and supplementing it with a heat potential far in excess of its losses through radiation and expansion.

10. The liability of any coal dust to explosion increases almost directly with its percentage of volatile matter that is combustible, *i.e.*, the quotient of its percentage of volatile matter divided by the sum of the percentages of volatile matter and fixed carbon.

11. While coal dust alone, under the conditions enumerated, is distinctively explosive, the presence of even the smallest amount of methane augments materially the susceptibility to ignition.

12. On account of the great elasticity of air, it is highly probable that no proper conception has yet been attained of the almost incredible speed with which a dust explosion, through its gaseous products, may be extended to far distant portions of a mine, under the force of initial expansion, properly called the "percussive theory."

13. Changes in barometric pressure only affect the liability to explosion in so far as they allow, when the barometer is falling, a settling of any possible accumulation of methane from a dome in the roof rock into the ventilating current; but such small quantities of gas are infinitely safer when diffused in the current of air than when concentrated in one place.

Moreover, even if it is granted that a low barometer allows greater occlusion, it also allows easier ventilation for the diffusion of such occlusion.

14. A mine may be over-ventilated until the air current has such a velocity that it stirs up dust, and would feed any slight ignition which might take place and otherwise die out. (*See* Q. 114.)

15. The difference in the amount of real dust made by either air punchers or electric chain machines is so slight and so variable, depending on the nature of the coal and the skill of the machine man, that it cannot be said that either machine, as a class, creates more dust than the other.

16. The results of experiments with electric ignition of dust show that the danger from electric wiring is no greater than that of stirring up a cloud of dust from a broken air pipe or a loose connection.

17. Coal dust cannot be made wet, in the usual sense. The method used by Superintendent Butler is indicative of the best results, but even then it is hypothetical if the most careful system of watering is not merely an infinitesimal portion of the "ounce of prevention," and it is an open question whether it is not positively detrimental. (*See* Q. 107.)

18. While the abolition of all explosives, as recommended by the Belgian authorities, appears unnecessary and impracticable in this country,* yet the greatest field of investigation now lies along that line, and only those explosives carefully tested, and known to be uniformly prepared, by well-known and responsible manufacturers should be used.

107.—Explain the Objects of the Coal Dust Experiments at Altofts.

The British Royal Commission on Mines now sitting took evidence on the subject of coal dust during the early part of this year,† their inquiries being directed towards (1) the part played by coal dust in engendering and fostering explosions in mines; (2) the means to prevent such explosions; and (3) the means to prevent the extension of such explosions. In consequence of the failure of the Commission to obtain unanimous expression of opinion from witnesses as to the efficacy of the numerous methods suggested for allaying explosions, it was decided to institute experiments in order to definitely settle if possible such differences of opinion as exist in regard to this important problem.

Mr. W. G. Garforth, chairman of Messrs. Pope & Pearson's Colliery Co., Ltd., Prof. Wm. Galloway, Mr. W. H. Atkinson (H.M. Superintending Inspector of Mines for South Wales) and Mr. Henry Hall (H.M. Inspector of Mines for the Liverpool District) were selected to advise the Royal Commission.

This advisory committee concluded that an installation of the dimensions and character necessary for carrying out experiments on a large scale, and over an extended period, could be erected and maintained at an inclusive cost of £10,000,

* U.S. America. † 1908.

and the Commission accordingly recommended that this sum should be raised by the Government and the coal owners in equal proportions.

For various reasons, however, the Government were unable to allocate the sum required for this purpose, and eventually the Mining Association of Great Britain decided to raise the whole of the necessary funds by means of a levy on a tonnage basis, to which all the collieries have subscribed.

It was ultimately decided to erect a gallery at Altofts, full particulars of which, and of the first series of experiments, may be found in the "Colliery Guardian" of August 28 and September 4, 1908, and the "Iron and Coal Trades Review" of September 4, 1908.

In view of the immense amount of information on the coal dust theory which has been accumulated during the past 25 years, "it is difficult," says the *Colliery Guardian*,* "to understand how there could exist two opinions as to the ability of coal dust to setting up a dangerous explosion in a mine in the absence of fire-damp. Yet there is a considerable body of expert opinion still opposed to this view, even in spite of the large quantity of experimental evidence in its favour and the reports of the Royal Commissions in England, Germany and Austria, all of which endorse the theory of coal-dust explosions. It will be interesting, therefore, to examine the reasons why these results have not been unanimously accepted. The opponents of this theory have offered the following criticisms of the experimental evidence. In the first place, they state that none of the experiments have been made under the same conditions as exist in an ordinary working coal-mine. The quantity of dust used in the experiments is usually far in excess of what would be normally present even in the most dusty mine. The obvious answer to this latter objection is that we do not know to what extent a blown-out shot may stir up the dust in a mine at the moment preceding an explosion. A further objection was that the experiments hitherto performed were on too small a scale. The experimental gallery, they say, should be as

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* September 4, 1908, pp. 454-5.

large as an ordinary mine gallery, and should be from 200 yds. to 400 yds. in length or even longer. Then, again, with regard to the absence of fire-damp. It has been urged that there has been no certainty that fire-damp was absent in many of the previous tests. Of course, it is difficult to prove the complete absence of fire-damp, especially when Prof. Bedson's experiments on the gases occluded by coal dust are recalled. But it is comparatively easy to prove the presence of any appreciable quantity of fire-damp by the simple process of testing the gallery air before each experiment. Quantities of occluded gas too minute for chemical detection would scarcely be of practical significance in connection with colliery workings.

"Although many of the previous experiments, and notably those of Mr. H. Hall, had come very near to the observance of these conditions, objections were still raised against the legitimacy of the deductions drawn from them. A common form taken by these objections was the unlikelihood of coal dust being a source of danger, seeing that some 20,000,000 shots are fired every year in this country, a large proportion of them being in dry and dusty mines, and yet explosions are comparatively rare.

"The Royal Commission of 1894 made the obvious reply to this objection. In order to set up an explosion there must be a combination of circumstances which probably rarely occurs in the practical working of a mine.

"When we consider what these factors are, the difficulties of controlling them in practical experiments becomes obvious. The main factors, so far as our knowledge at present goes, are probably the following :—

"1. The chemical character of the dust.

"2. The physical character of the dust.

"3. The quantity of dust present and its suspension in the air.

"4. The distribution of dust zones in the gallery.

"5. The nature of the flame causing ignition.

"6. The position of the shot.

"7. The dimensions of the gallery.

"8. The condition of the atmosphere as regards temperature, pressure and humidity.

"9. The velocity of the ventilation current.

"10. The volume of air and its relation to the volume of dust.

"11. Heat conductivity of the material forming the walls of the gallery.

"It is, however, quite possible that there are other factors not yet appreciated, amongst which some would be inclined to place the heating effect due to compression waves caused by the initial concussion, to which we have already alluded above. The time factor is also by no means a negligible quantity, especially in connection with the heat conductivity.

"The primary object of the Altofts tests, therefore must be considered to be, in the first place, of a confirmatory character. They have been designed with the special object of overcoming the objections that have been made to the experiments previously carried out, and the results already achieved cannot fail to carry conviction with regard to the important part which coal dust may play, even in the absence of any appreciable quantity of gas, in intensifying and even originating an explosion."

Having established the fact that coal dust is in itself explosive, the committee conducting the experiments next proceeded, according to the report in the "Iron and Coal Trades Review" above mentioned, to investigate preventive measures, particulars of which are quoted in the next answer.

108.—What Principal Remedies have been suggested for allaying the Dust Danger in Mines?

The three principal remedies suggested for allaying the dust danger in mines are :—

1. Watering.
2. Dustless zones.
3. Stone dust zones.

The first method is generally disliked, for, while it has many good points, its effect on the roof of the mine is a great drawback ; and not only does watering involve the danger of falls of roof, but it is almost impossible to effectually treat every crevice and dust-laden corner of the mine.

In regard to the second suggested remedy, even were it possible to maintain perfectly dustless zones (which is doubtful), it has still to be proved that these are an effectual preventive in cases of explosion. Experiments have shown that a very small quantity of dust will serve to propagate an explosion, so to be efficacious these zones would, in any case, require to be practically perfectly dustless.

There remains, then, the stone dust zone, and it is the effect of the stone dust zone that is now receiving particular attention at Altofts.

The presence of a certain amount of stone dust, Mr. Garforth claims, exerts a cooling influence on the blast, and on being stirred up also serves to dilute the coal dust in the atmosphere. Being heavy it also offers a decided resistance to the passage of an explosive blast. It will be remembered that Prof. Galloway originated the idea many years ago that stone dust might afford a means of safety. It has yet to be determined to what extent it is necessary to dilute the coal dust with stone dust in order to render it harmless; at the recent Courrières disaster it was ascertained that under certain conditions 46 per cent. of stone dust proved effective. This point, however, will be dealt with in the further experiments which are to take place.*

109.—Does water-spraying, in so far as it may make the air of a Mine damp, serve to prevent the spread of an Explosion?

It may be doubted whether moist air is a means of stopping explosions. Mr. Ashworth has pointed out (*Transactions* I.M.E., Vol. XXXIII., p. 193) that no form of water, excepting steam, could saturate an air-current sufficiently to place a barrier in front of a gas or dust explosion. Roughly estimated, air would have to contain over 5 per cent. of water vapour, or, say, 26 grains per cubic ft., before it could exercise any controlling influence. Mr. Ashworth further deduced from the hygrometrical observations taken at Wingate Grange that air saturated with moisture was no protection against the extension of an explosion. On the other hand, it assisted in the oxidation process; and moreover, in addition, the explosion

* *See* Appendix III. for particulars of later experiments.

(Wingate Grange) was reported to have passed over two wet places of considerable length.

In the same connection reference may be made to the explosion which took place at the Count Schwerin Pit, Dortmund, on Sept. 26, 1900. Two dynamite cartridges were fired (without certain prescribed safety cartridges, and contrary to regulations) all but simultaneously, and the dust created by the first, together with that whirled up from floor and sides, was ignited by the second shot. Firedamp was not found in the workings either before or after the explosion. The report states that " although it seems clear that the water-spraying apparatus was at work up to the moment when the shots were fired, this evidently did not suffice to lay properly all the coal-dust in the immediately neighbouring workings." (*Transactions* I.M.E., Vol. XXVI., 1903-4.)

Dr. Henry H. Payne has recently stated before the Coal Mining Institute of America (June, 1908) that " Coal-dust cannot be made wet, in the usual sense. The method of fine spraying is indicative of the best results ; but even then, it is hypothetical if the most careful system of watering is not merely an infinitesimal portion of the ' ounce of prevention,' and it is an open question whether it is not positively detrimental."

A similar trend of expert opinion is evidenced in the Report of the Commission appointed by the Societé de l'Industrie Minérale to investigate the causes of coal dust explosions, which approves of local, but not of general watering, and recommends that shot-firing be allowed in coal up to charges of 13½ oz. without previously laying or removing the dust.

110.—To what extent has watering served to prevent Explosions in the Midland District (England)?

As regards the Midland Mines Inspection District there does not appear to be any evidence that watering would have prevented any explosion which has ever occurred. Table IX., showing the number and cause of all the explosion fatalities from 1872 to 1905 indicates that of the 36 fatal explosions which have occurred during this period 35 are directly traceable to either the use of naked lights or defective lamps. Mr. Stokes, H.M. Inspector of Mines, in his report for the year 1900 attributes the decrease in the number of explosions not to watering or to the use of permitted explosives, but to the increased use of safety lamps, these comprising 67 per cent. of the total number of lights.

Referring to the period 1888–1892, during which no death occurred from explosion of fire damp, Mr. Stokes says: "This good result cannot be due to the scarcity of fire-damp in the mines, for many mines in the district would be classed as fiery, and occasionally enormous outbursts of gas occur." (1900 Report, p. 30.)

Only one explosion has been caused by gunpowder during the 34 years referred to in the table, and this notwithstanding the fact that so recently as 1905 the number of shots fired was 162,904 more than in 1902 and 63 per cent. of the total number were gunpowder and bobbinite (44 per cent. gunpowder, 19 per cent. bobbinite).

TABLE IX.—*Showing the Number and Cause of the Explosion Fatalities in the Midland Inspection District from* 1872 *to* 1905.

YEAR.	Number of		CAUSE OF EXPLOSION.
	Expl's'ns.	Deaths.	
1872	7	7	All gas ignitions by naked lights.
1873	4	4	,, ,, and defective lamp.
1874	3	3	,, ,,
1875	1	1	Gas ignition by naked light.
1876	1	6	,, ,,
1877	1	1	, ,,
1879	1	1	,, ,,
1881	4	4	,, ,, and defective lamp.
1882	4	70	,, ,,
1883	1	2	,, ,,
1884	1	1	,, ,,
1886	1	2	,, ,,
1887	1	1	,, ,,
1893	1	2	,, ,,
1895	1	7	Alleged dust explosion from overcharged gunpowder shot.
1897	1	1	Gas ignition by naked light
1900	1	2	,, ,, (" no gas had been previously found in the seam." —*Inspector's Report.*)
1904	1	2	Gas ignition by safety lamp.
1905	1	3	,, ,, naked light.

111.—Does the use of a Permitted Explosive provide exemption from watering—on the assumption that it "is of such a nature that it cannot inflame Gas or Dust"? (Gen. Rule 12 (*h*) (2)).

Mr. J. B. Atkinson, H.M. Inspector of Mines, in his Report on the circumstances attending the explosion which occurred at Washington Glebe Colliery, Durham, on Feb. 20, 1908 (Cd. 4,183), comments on the general interpretation of the Coal Mines Regulation Acts and Explosives in Coal Mines Orders, and states that a claim of exemption from watering cannot be upheld. "It may well be, however, that shot-firers look upon permitted explosives in this light, and do not take precautions such as they would take if using gunpowder. This would be a veritable playing with fire. I do not altogether share the view held by some of my colleagues, that the decline in explosions in recent years is principally due to the employment of permitted explosives. I think it is more probably due to the increased knowledge of the causes of explosions generally, and unless it is insisted on that no explosive that gives off flame or heat should ever be used unless where it would be perfectly safe to fire a gunpowder shot, the use of permitted explosives may become a source of danger rather than of safety. Safety should be sought outside the shot-hole and the use of permitted explosives should only be looked upon as an additional safeguard. In the north of England within 16 months four explosions due to permitted explosives have occured, viz., at Wingate Grange Colliery on Oct. 14, 1906, due to geloxite, and causing the death of 24 persons; at Urpeth Colliery on Dec. 17, 1906, due to westfalite No. 2, causing the loss of four lives; at Whitehaven Colliery on Nov. 26, 1907, due to saxonite, causing the loss of five lives, and the present case. This is a worse record so far as the North of England is concerned than ever occurred when the use of gunpowder was universal. The use of explosives that give off heat or flame must always be attended with some risk in gaseous and dusty mines, but believes that with a thorough appreciation of the conditions under which danger may arise and a rigid adherence to the statutory regulations the risk may be made very small. If the main roads of mines were kept free from coal-dust this risk would usually be confined to one district, and then, having regard to the fact that the danger from coal dust at the working face is so much less than when it is present in a state of very fine division (accompanied by swift air-currents capable of maintaining and carrying forward a cloud), blasting might be permitted at the face in some dry mines in the first working of the board-and-pillar system and in long wall workings, with some provision as to watering or removing dust somewhat different to those contained in General Rule 12 (*h*) (2), and with some provision as to the planting of shots so as to obviate the possibility of a cloud of dust being raised from the floor."

112.—At what rate is Dust deposited on Underground Roadways?

Mr. Henry Hall, I.S.O., H.M. Inspector of Mines, has recently* pointed out that before any useful suggestions could be made as to the treatment of coal dust, so as to render it innocuous, it was absolutely necessary to obtain some idea as to the rate at which dust is deposited on underground roadways. As a result of some experiments carried out in furtherance of the above inquiry, it has been shown that something like 11½ lb. of coal dust were carried in eight hours past the point where the measurement was taken. The velocity of the current of air carrying this dust was 95 cubic ft. per minute. The measurements for dust in the air were made with a bellows aspirator, and it was found that in 3 cubic ft. of air the amount was 0·002, 0·001, 0·002 and 0·0005 gramme, depending on the point of measurement. These results show that there was a gradual diminution of the dust as it travelled outbye.

A third method of measurement was adopted, with the object of arriving at the quantity of dust deposited on the floor, sides,

* Annual general meeting of the Institution of Mining Engineers at Edinburgh, September, 1908.

&c., as it was being carried along by the ventilating current. Flat porcelain dishes, of an area of 1·12 sq. ft., were used, two of which were placed at points on the main intake and two on the main return. These were in operation for periods varying from 8 to 10 hours on two separate days. The dust passing the two points on the main intake must have come partly from the screens and partly from the tubs passing up and down the shaft (about 600 tons of coal passed up the shaft each day).

The results show that at the shaft bottom, where the area of the road is 150 sq. ft., something like 11·47 grammes of dust were passing in the air each minute when the velocity was 225 ft.—that is, 18 lb. in six hours. So that at least this quantity is being deposited each working day on to the floor and ledges of the main road between the bottom of the shaft and the bottom of the tunnels 3,000 ft. inbye. If it be assumed that this road averages 12 ft. in width and that ½ lb. of dust per lineal foot of such a road is required to make an explosive mixture of dust and air, starting with a clean sheet it would require 83 ordinary working days to render this 3,000 ft. of road absolutely dangerous. (*Note.*—The deposit, of course, will be thicker near the shaft than further in.)

An interesting experiment was made at Garswood Hall Colliery. The screens at this colliery are near the downcast shaft, and a considerable quantity of dust is made in the process of screening, some of which finds its way back into the mine along with the ventilation. To obviate this, water-sprays have been fitted up at the bottom of the shaft, and also a frame has been put in the main airway a little distance from the shaft; arranged around this frame are several sprays, the object of which is to wash the dust from the air as it passes through the frame. Quite a considerable amount of dust is thus washed out. With 40,000 cubic ft. of air passing through, 7½ lb. (weight after drying) of dry dust was recovered by means of a settling tank in 14 hours, and probably as much more escaped collection, which means that the sprays washed down 14 lb. or 15 lb. in the 14 hours. The dust would originate partly at the screens and partly be blown from the trams in the pit shaft.

The total quantity of dust finding its way back on to the roadways must be very large, when with one frame only so much can be recovered.

These experiments, made with the view of getting an idea of the rate of accumulation of dust in mines under ordinary working conditions, should be carried much further ; but, so far as they go, it seems clear that the common estimate of the quantity of dust deposited day by day far exceeds the actual facts ; and it follows that when once the roads have been made thoroughly clean, to keep them so ought not to present any insuperable difficulty. Allowing dust to get back into the workings from the shafts and screens amounts to poisoning the ventilation before it starts on its duty.

113.—Describe a method of preparing a Dustless Zone.

Mr. A. M. Hedley recently described an effective combination of brushing and watering which had been employed by Mr. R. Crombie.

He would assume that a length of 300 ft. was required to be cleared of dust on a main haulage road, which at the same time served as an intake airway. On the inbye side (or the outbye side, if a return airway) of this area to be treated, a piece of brattice cloth, thoroughly soaked in water, was attached along its upper edge to the roof timber, across the full width of the road. It was hung at such a distance from the roof as was deemed necessary, without offering too great an obstruction to the ventilating current ; and, in the case of a strong current of air, the canvas should be weighted by attaching pieces of timber to its lower edge. When the brattice cloth was fixed, the dust zone was treated by water-sprays to such an extent as the nature of the seams roof or thill would allow, and it was then found that the operation of brushing the dust from the roof and sides could be carried out with impunity. The light dust raised, if carried forward by the air current, would, on meeting the wet canvas obstruction, be moistened and fall in layers on to the floor, whence, with the bottom dirt it could be removed and filled into a tub when the operation was completed. Possibly a succession of wet sheets might even give better results, and wet canvas stretched along the roof and sides would further improve matters. It was possible that one sheet, treated with a continuous spray of water throughout the brushing operation, would answer the required purpose. It appeared to him (Mr. Hedley) that the efficacy of this treatment depended on the fact that the dust was driven against a wet surface, instead of the water being thrown on to the dust and so acting as an agitating and disturbing agent.

114.—Is it possible, in connection with the Dust Danger, for a Mine to be too well ventilated?

Mr. Donald M. D. Stuart in discussing the Wingate Grange Explosion (*Trans.* Inst. M.E., Vol. XXXIII., pp. 183-4) noted that this colliery had been worked for over 40 years without any explosion or ignition of coal-dust and yet an explosion had originated in coal-dust in the main intake-airway where over 26,000 cubic ft. of air was passing per minute, and where gas could have no existence. The inquiry arose, whether the coal-dust possessed explosive properties during the 40 years of immunity from explosion, or whether they were of recent development.

The effect of air currents sweeping through haulage roads had been often observed, and here the moisture must have been largely absorbed in a period of 40 years; but in some mines both deposition of coal-dust and withdrawal of moisture were gradual, and might extend over many years before the danger stage was reached.

It also appeared that up to a recent year the mine was adequately ventilated by a fan producing 102,000 cubic ft. of air per minute; but subsequently the new fan had yielded nearly twice the quantity, namely, 193,478 cubic ft. If this increased quantity of air was taken through the original intake-airways, the velocity of the currents must have been considerably raised, accelerating the absorption of moisture, increasing leakage from the tubs, and adding to the coal-dust deposits in the haulage roads. One effect of the increased ventilation would therefore be dry intake airways and a more abundant supply of coal dust; another, the increased sensitiveness of coal dust after exposure to air currents, which had been observed by Prof. P. P. Bedson. These circumstances suggested that the explosive properties of the coal-dust might have been of recent development, and this was consistent with the fact that the explosion occurred after the changes in the ventilation.

He (Mr. Stuart) had found similar circumstances in his investigations at the Camerton and Timsbury Collieries. Both mines had been worked with immunity from explosion for from 70 to 100 years; but the ventilation was largely increased with no alteration in the dimensions of the intake airways, whereupon explosive properties developed in the coal dust distributed in the haulage roads, and extensive explosions occurred.

The ventilation of mines had claimed principal attention in past legislation, with limitation of view to dilution and removal of gas; but the time had now come when another factor of even more disastrous energy had to be considered, since it was evident that while large quantities of air, necessarily travelling at a high velocity, would dilute and render harmless noxious gases with a large margin of safety, they at the same time developed a more serious danger in creating explosive conditions throughout the main arteries of the mine, that needed only kindling at one point, to traverse the whole.

Considerable labour had been spent for many years in the almost hopeless mission of obtaining explosives that would not ignite gas or coal-dust in mines; the subjects of dust-tight tubs and watering haulage roads were now receiving much attention, but the potent relations of air-currents to the coal-dust question appeared to have been overlooked.

With air-currents at velocities of 400 to 800 ft. per minute, and loaded tubs travelling in the opposite direction at equal speeds, depositions of coal-dust along the arteries of the mine, and development of explosive properties in the dust, appeared to be almost unavoidable; and he (Mr. Stuart) suggested that regulation of the ventilation to remove noxious gases with least effect in creating dangerous coal-dust claimed serious attention.

115.—Do you think that under any conditions it would be possible for the Blast in an Explosion to separate the Dust and to take along with it that which was Coal-Dust pure and simple and to leave the other Dust which was mechanically mixed with it? (Q. 17,820, Mines Commission.)

I think if the force of the initial explosion were great enough, and the difference of the specific gravity of the coal and the foreign material were great enough too, the fine coal-dust might be raised—especially the fine-coal-dust near the top might be raised by itself—and therefore, you would have a very pure coal-dust. (J. T. Forgie, before Royal Commission on Mines.)

116.—To what extent may the Disease known as Nystagmus affect the Risks of Shot-firing?

Nystagmus is a disease of the eyes which is peculiarly associated with collieries although not confined to coal miners. The symptoms of the disease are horizontal oscillations of both eyes, vertigo and night blindness. Apart from the difficulty caused by the constant movement, clearness of vision is not affected and there are no organic changes in the eye.

The late Dr. Simeon Snell, the well-known authority on nystagmus, raised a point* in connection with this disease which may prove to have an important bearing on the cause of mine explosions. Fire-damp is ordinarily detected in coal mines by reducing the size of the oil flame of the safety lamp until the luminosity almost disappears; the fire-damp then, if present, appears as a pale blue flame or "cap" above it,

* Presidential Address to the British Medical Association for 1908-9 at Sheffield.

this "cap" being due to the presence of gas in the air. Dr. Snell has from time to time particularly mentioned in his writings the presence of nystagmus among deputies and others who are chiefly responsible for seeing that the pit is free from dangerous quantities of gas. For long—he proceeds to state in his address—it was his opinion that the apparent dancing of the safety lamps which forms such a prominent sympton of miners' nystagmus would, in especially well-marked instances, be a hindrance to the delicate detection of a "cap." These observations led Dr. Snell to test practically a number of those suffering from nystagmus as to their capacity to recognise the "gas cap" over the flame of a safety lamp.

Forty-eight miners, from 13 different collieries, were examined, and their incapacity to detect a "gas cap" unless a dangerous amount of gas was present, was very marked in all. One did not see a big "gas cap" as he said the lamp was "spinning too much," another did not see a small cap at all, but when he had steadied his eyes he recognised a 1 in. cap. Another could not see a cap because the lamp appeared to be all jerking about, but when the eyes became steadied, and the lamp ceased to spin round, he could recognise a gas cap. Another, in whom the nystagmus was slight, could only see a large cap. Another, in whom the nystagmus was very marked, reeled like a drunken man when rising from the position on the floor he had assumed as for work. The lamp was full before he detected a cap. In another the whole lamp appeared to be "swinging round," and he could see no cap until the lamp was full of blue flame. There were several who saw either only a large cap or a moderate sized cap when they had steadied themselves.

The method of steadying the eyes referred to consisted of resting the eyes by turning them directly downwards, when the oscillations ceased* or became much less marked. Thus, another man could not see a small cap when the lamp was "moving," but could do so after the eyes were steadied, and he

* All the miners tested were under treatment for nystagmus at the Sheffield Royal Infirmary.

Fig. 71.

Fig. 72.

Fig. 73 is, of course, only intended to give an idea as to the indistinctness occasioned to the miner by the apparent movements of the lamp, and is not designed to convey an exact representation of what is actually observed by him.

The point raised by Dr. Snell may prove of considerable importance, especially as no exact data is available as to the prevalence of nystagmus in British mines. If, as Dr. Snell estimates, the proportion of miners affected is only about 4 per cent., then the percentage of shot-firers so affected becomes so low as to eliminate all risks. On the other hand, it is difficult for one individual to obtain sufficient data in cases of this kind to form a reliable estimate, and it is possible that the proportion is far higher than has hitherto been supposed.

117.—What are the most important Safeguards against Explosions from Shot-firing?

1. Selection of the most suitable explosive (see Q. 101, p. 132).

2. Selection of intelligent and conscientious shot-firers, who are known by the Manager of the mine to possess sufficient technical knowledge, and have proved to him their ability to find the smallest percentage of gas that can be discovered with the type of lamp they use.

*3. The use by shot-firers of a safety-lamp that will indicate 0·5 per cent. of gas.

*4. Absolute prohibition of shot-firing where gas is present in excess of 1 per cent. of the mine air.

5. Absolute prohibition of shot-firing on main haulage roads, without a written authority from the Manager.

6. Rigid adherence to shot-firing regulations.

118.—What Qualifications and Information ought a Fireman or Shot-firer to possess?

A competent shot-firer or fireman should be conscientious and trustworthy and self-reliant, and should be a good pitman. He should know well the Coal Mines Regulation Acts and Explosives in Coal Mines Orders, and be physically and otherwise capable of testing for minute quantities of gas.

* *See* Appendices I. and II.

He should know at least as much electricity as will enable him to understand the meaning of Ohm's Law and as much chemistry as will enable him to understand what is meant by such expressions as, for instance, "chemical combination," "combustion," and "detonation."

He should also know why it is dangerous to fire shots in unstemmed holes, in the presence of coal-dust, fire-damp, or mixtures of the two, and generally otherwise than in strict accordance with the regulations for the time being in force.

Prof. Galloway has expressed the opinion* that every official who is appointed to fire a shot in a fiery, dry and dusty mine, should, before being authorised to do so, have gone through a course of practical training in examining for gas, and obtained a certificate that he has passed through that training; and in the event of anything happening in a place in which he has fired a shot, such as a small explosion of fire-damp, that certificate ought to be withdrawn and the man punished, because it is absolutely impossible for an explosion to take place where a shot is fired unless there is gas present in the place before the shot is fired.

Mr. R. S. Williamson, general manager of the Cannock and Rugeley Collieries, Staffordshire, has stated in evidence before the Royal Commission on Mines now sitting that before appointing a fireman he puts a series of questions unless he has sufficient personal knowledge of the candidate.

Mr. Williamson's series of questions, which follow, is considered to embrace the duties of fireman or deputy and is one which may well be commended to officials not only in Staffordshire but in other mining districts :—

"(1) Name ? (2) Age ? (3) In what capacity has the applicant been ? (4) How long ? (5) Are you sober, and are you regular at work ? (6) Have you lost much time by absenting yourself ? (7) For what purpose was the 1887 Coal Mine Act made ? (8) What are the duties of a competent man ? (9) What is ventilation, and how is it arranged ? What does 'coursing the air' mean ? (10) Give the names of the

* Minutes of Evidence of the Bobbinite Committee, p. 29.

different appliances in connection with ventilation. (11) How much air per minute is necessary to ventilate a long wall work—500 yds. long ? (12) How would you carry the air so as to comply with the requirements of the Act of Parliament ? (13) What gases are met with in mines when a blue cap or halo is seen in the flame; what does this mean, and would you allow blasting where such is the case ? (14) What gas is found in wastes and about the roof of mines ? (15) Does the coal, roof or the bottom of the mine you have been employed in yield gas ? (16) How would you deal with bodies of inflammable gas in the mine whilst the workmen are engaged with their work, and how far would you allow naked lights to go back in the wastes ? What is used to ventilate wastes ? (17) When ought safety lamps to be used ? (18) Whose duty is it to examine safety lamps according to the Coal Mines Act ? (19) How would you examine a safety lamp, and when should you consider it dangerous ? (20) How many apertures are there in a square inch of gauge, and if one of these apertures was broken what would you do ? (21) Give the name and describe the lamp you consider the best and safest for use in mines. (22) At what velocity do the above lamps explode, supposing they are in an explosive atmosphere ? (23) Under what conditions ought blasting to be allowed in a mine yielding inflammable gas ? (24) Who ought to give the order for blasting in mines where it is allowed ? (25) What precautions are necessary for the men to take in preparing to blast ? (26) What are the duties of the competent man in connection with blasting ? (27) What parts of the mine ought to be examined before blasting is allowed ? (28) Supposing a body of gas to be existing in the part of the mine where you sanction blasting, at what distance from the gas would you consider it safe to blast ? (29) What ought to be done after a shot has been fired ? (30) What do you know about timbering roads and working faces ? (31) How would you timber a face of work with a bad roof ? (32) Supposing the roof of a stall begins to weight heavily, what should you do ? (33) What precautions are necessary in drawing timber ? (34) At what distance, when and where ought sprags to be set or used on the face of work ? (35) How do you examine the roof and sides of the mine ? (36) What do you do after finding the roof and sides of working places and travelling roads dangerous ? (37) Supposing you found a workman breaking the rules, and endangering his own and other people's lives, what would you do ? (38) In a mine yielding gas, how does a falling barometer and a rising thermometer affect it ? (39) What is a barometer ? (40) What is a thermometer ? (41) Supposing you had a body of gas in a waste or gob, how would such a body of gas be affected by a rise of temperature in the mine ? (42) Supposing the fan ceased to act and the ventilation of the mine ceased, what would you do ? (43) Whose duty is it to see every workman in the mine frequently during work hours, and also to see the mine cleared of workmen ? (44) Supposing you have eight or ten stalls under your charge, how often during a working shift of eight hours would you visit each stall ? (45) Just describe to me what sort of an examination you would make in each stall and gob road ? (46) What is the Coal Mines Act of 1887 ? (47) What are the General Rules and where are they taken from ? (48) What are the Special Rules and for what purpose were they made ? (49) Supposing a workman to violate any of the Special Rules, how could he be punished ? (50) Now describe to me the General Rules relating to your duties ? (51) Describe the Special Rules relating to your duties. (52) How long previous to workmen commencing work has his working place to be examined by the competent man ? (53) How many doors should be placed in the main roads between the upcast and downcast shafts ? (54) What is a water gauge used for ? (55) What does an inch on it represent as regards pressure ? (56) What would you expect with a sudden rise in the water gauge ? (57) Where should regulators be placed; what are they used for ? (58) Which should be the largest, intake or return ? (59) Why ? "

CHAPTER V.

LAWS AND REGULATIONS RELATING TO THE STORAGE AND USE OF EXPLOSIVES.

In this chapter the various Laws and Regulations now operative for the prevention of accidents arising out of the storage and use of explosives are brought together in order to facilitate the study of them and to provide a convenient source of reference.

There can be no doubt that the Regulations constitute a valuable guide and means of protection to all who, by reason of their occupation or in other ways, may become liable to explosive risks. To those who come within the authority of these edicts compliance with them is, of course, compulsory, but apart from this it is clear to anyone who knows of the strange and unexpected ways in which blasting accidents often occur that not a single rule has been drafted without excellent cause. Consequently they demand the most careful attention.

Elementary—almost absurdly elementary—some of the instructions will appear to be, and, perhaps, having regard to the extension of scientific knowledge, and the tardy but still notable and definite development of general intelligence amongst working miners, it may soon be found possible to re-cast and materially reduce the number without any diminution of safety.

119.—What Enactments regulate the use of Explosives and Blasting Apparatus in Mines and Quarries (in England)?

The use of explosives and blasting apparatus in mines and quarries is regulated by—

1. The Explosives Act, 1875.

2. The Quarries Act, 1894 (comprising certain provisions of the Metalliferous Mines Act, 1872 and 1875).

3. The Coal Mines Regulation Acts, 1887 to 1896.

4. The Special Rules for the Installation and use of Electricity in Mines, and

5. Explosives in Coal Mines Orders made from time to time by the Secretary of State in pursuance of sec. 6 of the Coal Mines Regulation Act, 1896.

120.—What is the Object of the Explosives Act, 1875?

The Explosives Act, 1875.

The object of the Explosives Act, 1875, is to control the manufacture, keeping, sale, conveyance and importation of explosives for legitimate purposes.

For the purposes of the said Act explosives are divided into seven classes as follows :—

Class I. ...Gunpowder	Class V. ......Fulminate
,, II. ...Nitrate mixture	,, VI. ......Ammunition
,, III. ...Nitro-compound	,, VII. ......Firework
,, IV. ...Chlorate mixture	

121.—Define the Seven Classes into which Explosives are divided under the Explosives Act, 1875.

Class I.—Gunpowder Class

The term "gunpowder" means exclusively gunpowder ordinarily so called.

Class II.—Nitrate Mixture Class.

The term "nitrate mixture" means any preparation, other than gunpowder ordinarily so called, formed by the mechanical mixture of a nitrate with any form of carbon, or with any carbonaceous substance not possessed of explosive properties, whether sulphur be or be not added to such preparation, and whether such preparation be or be not mechanically mixed with any other non-explosive substance.

Class III.—Nitro-compound Class.

The term "nitro-compound" means any chemical compound possessed of explosive properties or capable of combining with metals to form an explosive compound, which is produced by the chemical action of nitric acid (whether mixed or not with sulphuric acid) or of a nitrate mixed with sulphuric acid upon any carbonaceous substance, whether such compound is mechanically mixed with other substances or not.

The nitro-compound class has two divisions :—

Division I. comprises such explosives as nitro-glycerine, dynamite and any chemical compound or mechanically mixed preparation which consists either wholly or partly of nitro-glycerine or of some other liquid nitro-compound.

Division II. comprises such explosives as gun-cotton, ordinarily so called, nitrated gun-cotton, cotton gunpowder, Schultz's powder, and any nitro-compound as before defined which is not comprised in the first division.

Class IV.—Chlorate Mixture Class.

The term "chlorate-mixture" means any explosive containing a chlorate.

The chlorate-mixture class has two divisions:—

Division I. comprises any chlorate preparation which consists partly of nitro-glycerine or of some other liquid nitro-compound.

Division II. comprises any chlorate mixture as before defined which is not comprised in the first division.

Class V.—Fulminate Class.

The term "fulminate" means any chemical compound or mechanical mixture, whether included in the foregoing classes or not, which, from its great susceptibility to detonation, is suitable for employment in percussion caps or any other appliances for developing detonation, or which, from its extreme sensibility to explosion, and from its great instability (that is to say, readiness to undergo decomposition from very slight exciting causes), is especially dangerous.

This class consists of two divisions:—

Division I. comprises such compounds as the fulminates of silver and of mercury, and preparations of these substances, such as are used in percussion caps; and any preparation consisting of a mixture of a chlorate with phosphorus, or certain descriptions of phosphorus compounds, with or without the addition of carbonaceous matter, and any preparation consisting of a mixture of a chlorate with sulphur, or with a sulphuret, with or without carbonaceous matter.

Division II. comprises such substances as the chloride and the iodide of nitrogen, fulminating gold and silver, diazo benzol, and the nitrate of diazo benzol.

Class VI.—Ammunition Class.

The term "ammunition" means an explosive of any of the foregoing classes when enclosed in any case or contrivance, or otherwise adapted or prepared so as to form a cartridge or charge for small arms, cannon, or any other weapon, or for blasting, or to form any safety or other fuse for blasting or for shells, or to form any tube for firing explosives, or to form a percussion cap, a detonator, a fog signal, a shell, a torpedo, a war rocket, or other contrivance other than a firework.

The term "percussion cap" does not include a detonator.

The term "detonator" means a capsule or case which is of such strength and construction, and contains an explosive of the fulminate explosive class in such quantity that the explosion of one capsule or case will communicate the explosion to other like capsules or cases.

The term "safety fuse" means a fuse for blasting which burns and does not explode, and which does not contain its own means of ignition, and which is of such strength and construction and contains an explosive in such quantity that the burning of such fuse will not communicate laterally with other like fuses.

The ammunition class has three divisions:—

Division I. comprises exclusively: safety cartridges, safety fuses for blasting, railway fog signals, percussion caps.

Division II. comprises any ammunition as before defined which does not contain its own means of ignition, and is not included in Division I., such as cartridges for small arms, which are not safety cartridges; cartridges and charges for blasting or other like purposes; fuses for blasting which are not safety fuses; tubes for firing explosives which do not contain their own means of ignition.

Division III. comprises any ammunition as before defined which contains its own means of ignition, and is not included in Division I., such as detonators and fuses for blasting, which are not safety fuses, which do contain their own means of ignition.

By ammunition containing its own means of ignition is meant ammunition having an arrangement, whether attached to it or forming part of it, which is adapted to explode or fire the same by friction or percussion.

CLASS VII.—FIREWORK CLASS, COMPRISING FIREWORK COMPOSITION AND MANUFACTURED FIREWORKS.

122.—What are the principal Regulations as to storage of Gunpowder and Mixed Explosives?

The principal Regulations as to Storage of Gunpowder and Mixed Explosives are as follows :—

1. The store must be licensed by the local authority in the name of the occupier either for gunpowder or mixed explosives.

2. The licence must be renewed annually.

3. The store must not be situated below ground in any mine or quarry, or in any tunnel or other underground place, in which mine, quarry, tunnel or underground place any work is being carried on, or in which any persons are employed, or in any place opening into, from, or out of such mine, quarry, tunnel, or underground place, or in communication therewith.

4. The store may not be used for keeping explosives if at any time it is disqualified for the division under which it is licensed by failure to comply with certain regulations as to distance from protected works.

The latter are divided into four classes, and the distance ranges according to class, between 25 yds. and 2 miles.

The quantity of explosive that may be kept in the store shall not exceed :—

Store belonging to	Quantity.	
	Gunpowder.	Other explosives.
Division A	300 lb.	In lieu of each 1 lb. of gunpowder not kept, ½ lb.
,, B	1,000 ,,	
,, C	2,000 ,,	
,, D	4,000 ,,	

If two or more explosives are kept in the store, they must be separated from each other by an intervening partition of such substance and character as will effectually prevent explosion or fire in the one communicating with the other. This rule is, however, subject to the following qualifications :—

1. Explosives of Class I. (gunpowder), Class II. (nitrate mixture), Class III. (nitro-compound), Class IV. chlorate mix-

ture, safety fuse and such of the various explosives of the second division of the sixth (ammunition) class as do not contain any exposed iron or steel, may be kept with each other without any intervening partition. (For a few hundred detonators a cupboard in the porch of the store, so arranged that it cannot be opened unless the inner door of the store is closed, may be allowed. Detonators are weighed with their cases as part of the allowed quantity of explosive. No. 6 detonators —that is, No. 6 size copper shells with fulminate—weigh approximately 5 lb. per 1,000. No. 8 detonators weigh 8·66 lb. per 1,000.)

2. Explosives of the first division of the sixth (ammunition) class may be kept with each other without any intervening partition.

3. Explosives of the second division of the sixth (ammunition) class which contain any exposed iron or steel may be kept with each other without any intervening partition.

4. Explosives of the third division of the sixth (ammunition) class may be kept with each other without any intervening partition.

Electric fuses may be kept with detonators.

The store must be well and substantially built of brick, stone, or concrete, or excavated in solid rock, earth or mine refuse not liable to ignition, and so made and closed as to prevent unauthorised persons having access thereto, and to secure it from danger from without.

Particulars of other detailed regulations may be found in Capt. Thomson's official "Guide to the Explosives Act, 1875."

123.—What is the Quarries Act?

The Quarries Act, 1894. The Quarries Act (1894, 57 & 58 Vict., Chap. 42) applies certain provisions of the Metalliferous Mines Acts, 1872 and 1875, to all quarries more than 20 ft. deep.

124.—What is a "Quarry" under the Quarries Act?

A "quarry" under the Quarries Act, 1894, is any place (not being a mine) in which persons work getting minerals, any part of which is more than 20 ft. deep.

125.—Give the Special Rules under the Quarries Act relating to Blasting.

Following are the special rules under the Quarries Act relating to blasting:—

1. All explosives shall be conveyed from the magazine to the quarry, and kept till used in secure packages so made and closed as to prevent any escape of the explosives and any danger from sparks.

Every workman or gang of workmen possessing explosives shall keep them, when not in actual use, in his or their own locked box provided for that purpose exclusively. The interior of the box shall be kept clean and free from grit.

Detonators shall be kept in separate and secure boxes. No person shall smoke while carrying, handling or using explosives, or when near any person so doing.

When explosives require to be thawed, safe and proper warming pans shall be provided by the owner for that purpose, and no explosives shall be thawed by any other means or otherwise than in such warming pans.

2. No iron or steel tool shall be used for charging or stemming a hole with any explosive. Wooden rammers only shall be used for pushing in explosives.

No straw fuses shall be used. After firing a charge of any explosive no further charge shall be introduced into the hole nor into any rent made until after the lapse of 30 min.

3. Due warning shall be given by an efficient system of signals before blasting may be commenced, and when it is finished. In quarries where blasting occurs daily it shall as far as possible take place only at fixed stated intervals.

Where danger from blasting may arise to the public, efficient means shall be taken to give them due warning.

4. A sufficient number of proper shelters shall be provided (which must be used by the persons employed), except where all leave the quarry during blasting.

5. If a shot has apparently missed fire, no person shall be allowed to go near it until after the lapse of half an hour, except where electricity has been used.

The person or persons whose shot has apparently missed fire shall immediately give warning of the same. A shot that has missed fire shall not be unrammed, bored, or picked out. If it is necessary to bore a hole near a charge which has missed fire, care shall be taken to bore it in such a manner as not to affect or ignite the unexploded charge.

6. The quarry owner shall frame regulations as to intervals and signals for blasting, copies of which shall be kept constantly affixed in the quarry office, and in a sufficient number of places in and adjacent to the quarry.

126.—What Special Rules relating to Blasting are in force in the Ore Mines of North Wales?

SPECIAL RULES FOR ORE MINES IN NORTH WALES.

EXPLOSIVES AND BLASTING.

Metalliferous Mines Regulation Act, 1872.

1. No explosive shall be issued except to a person authorised by the Owner or Agent to receive it. A book shall be kept showing the date of delivery of the explosive, the amount delivered, and the name of the person or set to whom it was supplied. This book shall be produced to the Inspector on demand.

2. (*a*) The case or canister for holding explosives shall be of wood, horn, copper, zinc, or other substantial or solid material, so made and closed as to prevent any escape of the explosive, or any danger from sparks, and shall not be made of, or fitted with, iron or steel unless the same is effectually covered with tin, zinc, or other material.

(*b*) A bag or a paper or cardboard cover, box, or wrapper shall not be regarded as a substantial and sufficient receptacle or case, and such a case shall not be used alone.

3. When it is necessary that explosives shall be thawed artificially, safe and proper warming-pans shall be provided and used for that purpose, and the whole charge about to be used shall be evenly tempered.

4. Every workman or gang of workmen possessing explosives shall keep them in a secure chest. The chest shall be used solely for the keeping of explosives. No workmen or gang of workmen shall have more than one chest for keeping explosives other than detonators. The chest and its fittings shall be so constructed or so lined or covered as to prevent the leakage of any explosive and the exposure of any grit, iron, or steel, or similar substance, in such a manner as to come in contact with the explosives. The chest, when containing explosives, shall be kept locked, except during the operation of putting in or taking out explosives. All metal work in the locks, bolts, hinges, &c., shall be of brass, copper, or similar material. On the outside of the chest there shall be affixed the word "Explosives" in conspicuous characters by means of a securely attached label or otherwise.

5. No workmen or gang of workmen shall keep in his or their chest more cases or canisters of explosives than it is estimated will be required during the working day of one or more shifts.

6. When any explosive, such as dynamite, which is likely to be dangerously affected by water is kept in the chest due precaution shall be taken to exclude water from it.

7. The interior of the chest and all its fittings shall be kept clean and free from grit.

8. The chest shall be placed where it is not liable to be struck by stones from falls or blasts, or by tram-waggons, sleds, or their contents.

9. Explosives chests belonging to different parties or gangs of workmen shall be kept as far apart as possible.

10. Detonators shall be kept in a substantial locked box and placed where they are not liable to be struck by blows of any kind. Detonators or boxes containing detonators shall not be placed inside the explosives chests.

11. No unauthorised person shall have access to any chest or receptacle containing explosives.

12. No person shall smoke while carrying, handling or using explosives.

13. No tool made of iron or steel or partly of iron or steel shall be used for charging or stemming a hole with any explosive. Wooden rammers only shall be used for charging or stemming nitro-glycerine explosives No explosive shall be rammed with violence, or forcibly pressed into a hole.

14. Before firing shots under-ground due warning must be given to persons in the neighbourhood, and the persons firing the shots shall station themselves out of the way of danger, and so as most effectively to warn and protect other persons.

15. If a shot goes off but fails to do its work, a person shall not recharge the hole or put powder into any crack made, until after the lapse of 30 minutes.

16. If a hole has apparently missed fire, a danger signal shall at once be put up and no person shall be allowed to go near, except in case of emergency, until after the lapse of 30 minutes.

17. No part of the tamping or stemming of any hole charged with explosive shall be unrammed, bored, or picked out. In cases where it is practicable without removing any of the tamping, a charge that has missed fire shall not be left in the hole, but shall be exploded by firing a fresh charge on the top of it. Care shall be taken to bore new holes as far as possible from a missed charge of any explosive.

18. High explosives which require to be exploded by a detonator shall invariably be exploded by a detonator of sufficient strength.

19. When it is not necessary that shots should be fired simultaneously, care shall be taken to arrange the fuses so that the shots may go off in succession, so as to prevent the chance of a mistake about the number of reports.

20. All holes shall be examined after blasting to see whether any remnants of the explosives have been left behind; any such remnants of dynamite, blasting gelatine, gelignite, tonite, or any other explosive containing nitro-glycerine or gun-cotton shall be exploded by firing a detonator upon them.

21. No boring shall be done in or metal tool introduced into the bottom or socket of a hole which has been blasted with dynamite, blasting gelatine, gelignite, tonite, or any explosive containing nitro-glycerine or gun-cotton.

127.—Give the Requirements under General Rule 12 relating to Shot-firing.

The Coal Mines Regulation Acts 1887 to 1896.

The Coal Mines Regulation Acts provide a comprehensive set of rules designed to put an end to a number of common causes of accident. These rules are collected under General Rule 12, which enacts that any explosive substance shall only be used in the mine below ground as follows:—

(*a*) It shall not be stored in the mine.

(*b*) It shall not be taken into the mine, except in cartridges in a secure case or canister containing not more than 5 lb.—

Provided that on the application of the owner, agent or manager of any mine, the Secretary of State may by order exempt such mine from so much of this rule as forbids taking an explosive substance into the mine, except in cartridges.

(*c*) A workman shall not have in use at one time in any one place more than one of such cases or canisters.

(*d*) In the process of charging or stemming for blasting, a person shall not use or have in his possession any iron or steel pricker, scraper, charger, tamping rod or stemmer, and only clay or other non-inflammable substances shall be used for stemming, and shall be provided by the owner of the mine.

(*e*) No explosive shall be forcibly pressed into a hole of insufficient size, and, when a hole has been charged, the explosive shall not be unrammed, and no hole shall be bored for a charge at a distance of less than 6 in. from any hole where the charge has missed fire.

(*f*) In any place in which the use of a locked safety lamp is for the time being required by or in pursuance of this Act, or which is dry and dusty, no shot shall be fired except by or under the direction of a competent person appointed by the owner, agent or manager of the mine, and such person shall not fire the shot or allow it to be fired until he has examined both the place itself where the shot is to be fired, and all contiguous accessible places of the same seam within a radius of 20 yds., and has found such place safe for firing.

(*g*) If in any mine, at either of the four inspections under Rule 4 recorded last before a shot is to be fired, inflammable gas has been reported to be present in the ventilating district in which the shot is to be fired, the shot shall not be fired—

1. Unless a competent person, appointed as aforesaid, has examined the place where gas has been so reported to be present, and has found that such gas has been cleared away, and that there is not at or near such place sufficient gas issuing or accumulated to render it unsafe to fire the shot; or

2. Unless the explosive employed in firing the shot is so used with water or other contrivance as to prevent it from inflaming gas, or is of such a nature that it cannot inflame gas:

(*h*) If the place where a shot is to be fired is dry and dusty, then the shot shall not be fired unless one of the following conditions is observed, that is to say—

1. Unless the place of firing, and all contiguous accessible places within a radius of 20 yds. therefrom are at the time of firing in a wet state from thorough watering or other treatment equivalent to watering, in all parts where dust is lodged, whether roof, floor, or sides; or

2. In the case of places in which watering would injure the roof or floor, unless the explosive is so used with water or other contrivance as to prevent it from inflaming gas or dust, or is of such a nature that it cannot inflame gas or dust :

(*i*) If such dry and dusty place is part of a main haulage road, or is a place contiguous thereto, and showing dust adhering to the roof and sides, no shot shall be fired there unless—

1. Both the conditions mentioned in sub-head (*h*) (1)(2) have been observed ; or

2. Unless such one of the conditions mentioned in sub-head (*h*) as may be applicable to the particular place has been observed, and moreover all workmen have been removed from the seam in which the shot is to be fired, and from all seams communicating with the shaft on the same level except the men engaged in firing the shot, and such other persons, not exceeding 10, as are necessarily employed in attending to the ventilating furnaces, steam boilers, engines, machinery, winding apparatus, signals, or horses, or in inspecting the mine.

(*k*) In this act " ventilating district " means such part of a seam as has an independent intake commencing from a main intake air course, and an independent return airway terminating at a main return air course ; and " main haulage road " means a road which has been, or for the time being is, in use for moving trams by steam or other mechanical power.

(*l*) Where a seam of a mine is not divided into separate ventilating districts, the provisions in this act relating to ventilating districts shall be read as though the word " seam " were substituted for the words " ventilating district."

(*m*) So much of this rule as requires the explosive substance taken into the mine to be in cartridges, and so much of the provisions of sub-head (*f*) as relates to a dry and dusty place, and the provisions (*g*), (*h*), (*i*), (*k*), and (*l*) shall not apply to seams of clay or stratified ironstone which are not worked in connection with any coal seam, and which contain no coal in the working.

128.—What is the object of Special Rules, under the Coal Mines Regulation Act?

The object of Special Rules is to provide regulations beyond those contained in the general rules "for the conduct and guidance of the persons acting in the management of a mine or employed in or about a mine as, under the particular state and circumstances of such mine, may appear best calculated to prevent dangerous accidents and to provide for the safety, convenience and proper discipline of those employed in or about the mine."*

The establishment of special rules is compulsory in every mine under the Coal Mines Act, but not so in mines under the Metalliferous Mines Act.

129.—Give a set of Special Rules for Shot-firing in Mines.

Special Rules. Special Rules vary in different mining districts but generally include the following provisions :—

The Under-Manager and Deputies shall enforce the provisions of the Act and Special Rules relating to the use of gunpowder or other explosive substances in the mine.

No person shall, without authority, have in his possession in the mine any explosive. No person shall break any cartridge in the mine.

Explosives shall be kept in a box or case, which shall be securely locked, and no unauthorised person shall have access to the same.

No person shall fire shots without authority from the manager or under-manager.

No person shall have in his possession any iron or steel pricker, scraper, charger, tamping rod or stemmer, nor shall he use coal or coal dust for tamping.

Every person about to fire a shot shall, before firing, see that all other persons are out of reach of danger from the probable effects of such shot; and shall take means to prevent any person inadvertently approaching the place until such shot has gone, and immediately before firing shout "Fire."

Each deputy having charge of a district in which shots are to be fired shall, before commencing his shift, read the reports of the last four inspections of the ventilating district in which his district is situated, and note if any inflammable gas has been reported ; and if inflammable gas has been reported to be present in any part of the ventilating district, he must observe the requirements of General Rule 12.

After a shot has been fired, the person who has fired the shot, or some other competent person, shall, as soon as practicable examine the place, and, if necessary, take steps for its security.

Every case of a shot missing fire shall be reported to the under-manager or a deputy, by the person in charge of the shot at the time of the miss-fire.

* Sec. 51, C.M.R. Act, 1887.

130.—State the Shot-firing clauses in the Electricity in Mines Rules relating to Shot-firing from Power Cables in Sinkings and Stone Drifts.

Special Rules for the Installation and Use of Electricity in Mines.

The *Special Rules for the Installation and Use of Electricity in Mines* only contain three clauses relating to shot firing. They are as follows :—

Electricity from lighting or power cables shall not be used for firing shots, except in sinking shafts on stone drifts, and then only when a special firing plug, button or switch is provided, which plug, button, or switch shall be placed in a fixed locked box, and shall only be accessible to the authorised shot firer.

The firing cables or wires shall not be connected to this box until immediately before it is required for the firing of shots, and shall be disconnected immediately after the shots are fired.

When shot-firing cables or wires are used in the vicinity of power or lighting cables, sufficient precautions shall be taken to prevent the shot-firing cables or wires from coming in contact with the lighting or power cables.

131.—State the Provisions of the Explosives in Coal Mines Order now in force (September, 1908).

EXPLOSIVES IN COAL MINES ORDERS.

Explosives in Coal Mines Orders are issued under Sec. 6 of the Coal Mines Regulation Act, 1896, which enacts that a Secretary of State, on being satisfied that any explosive is, or is likely to become, dangerous, may by Order prohibit the use thereof in any mine or in any class of mines either absolutely or subject to conditions.

In pursuance of the power conferred by the above Section, a new Order was issued on December 17, 1906. This Order, which revokes and consolidates all previous Orders, came into force on March 1, 1907, and contains the following provisions :—

Absolute Prohibition of certain Explosives in Unsafe Mines.

1. (*a*) In all coal mines in which inflammable gas has been found within the previous three months in such quantity as to be indicative of danger, no explosive, other than a permitted explosive as hereinafter defined, shall be used in or taken for the purpose of

use into the seam or seams in which the gas has been found, or any shaft or drift communicating therewith which is in process of being deepened or sunk or being driven, as the case may be.

(*b*) In all coal mines which are not naturally wet throughout, no explosive, other than a permitted explosive as hereinafter defined, shall be used in or taken for the purpose of use into any road or any dry and dusty part of the mine, or any shaft or drift communicating, therewith which is in process of being deepened or sunk or being driven as the case may be.

Conditional Prohibition of other Explosives in Unsafe Mines.

2. In all such coal mines or parts thereof as aforesaid, the use of permitted explosives is prohibited unless the following conditions are observed:—

(*a*) Every charge shall be fired by a competent person (hereinafter called the shot firer) appointed in writing for this duty by the owner, agent or manager of the mine, and not being a person whose wages depend on the amount of mineral to be gotten.

(*b*) Every charge of the explosive shall be placed in a properly drilled shot hole and shall have sufficient stemming, and each such charge shall consist of a cartridge or cartridges of not more than one description of explosive.

(*c*) No cartridge shall be used unless it is marked in the manner set forth in the Third Schedule hereto, in addition to any marking required by the First Schedule hereto.

(*d*) No charge shall be fired except by means of an efficient electrical apparatus so enclosed as to afford reasonable security against the ignition of inflammable gas, or by a permitted igniter fuse, as hereinafter defined.

(*e*) Where the charge is fired by an electrical apparatus the shot-firer shall not use a cable for the purpose which is less than 20 yds. in length. He shall himself couple up the cable to the charge and shall do so before coupling the cable to the firing apparatus. He shall also himself couple the cable to the firing apparatus. Before doing so, he shall see that all persons in the vicinity have taken proper shelter. Should the charge miss fire, he shall immediately disconnect the cable from the firing apparatus.

(*f*) Every electrical firing apparatus shall be provided with a removable handle or safety plug or push button, which shall not be placed in position or operated until the shot is required to be fired and which shall be removed or released as soon as a shot has been fired. The removable handle or safety plug shall at all times remain in the personal custody of the shot-firer whilst on duty.

(*g*) Each explosive shall be used in the manner and subject to the conditions prescribed in the Schedules hereto.

(*h*) Where two or more shots are being fired in the same place and such shots are not fired simultaneously, the shot-firer shall make an examination for gas immediately before the firing of each shot and shall not fire the shot unless he finds the place where the shot is to be fired and all contiguous accessible places within 20 yds. free from gas and safe for firing

Provided that nothing in this order shall prohibit the use of a safety fuse in any mine in which inflammable gas has not been found within the previous three months in such quantity as to be indicative of danger.

Conditional Prohibition of all Explosives in Main Roads.

3. In every coal mine the use of any explosive is prohibited in the main haulage roads and in the intakes unless all workmen have been removed from the seam in which the shot is to be fired, and from all seams communicating with the shaft on the same level, except the men engaged in firing the shot, and in addition such other persons not exceeding 10 in number as are necessarily employed in attending to the ventilating furnaces, steam boilers, engines, machinery, winding apparatus, signals, or horses, or in inspecting the mine; or unless a permitted explosive is used under the conditions prescribed in Sec. 2 of this Order, and every part of the roof, floor, and sides of the main haulage road or intake, within a distance of 20 yds. from the place where it is used, is, at the time of firing, thoroughly wet, either naturally or from the application of water thereto.

This section shall not apply to such portions of the main haulage roads and intakes as are within 100 yds. of the coal face.

This section shall not authorise the use of any explosive in any case where the use of such explosive is prohibited by Secs. 1 or 2 of this Order.

Conditional Prohibition of Detonators.

4. Detonators shall not be used in or taken for the purpose of use into any mine unless the following conditions are observed :—

(*a*) Detonators shall be under the control of the owner, agent or manager of the mine, or some person or persons specially appointed in writing by the owner, agent, or manager for the purpose, and shall be issued only to shot-firers or other persons specially authorised by the owner, agent or manager in writing.

(*b*) Shot-firers and other authorised persons shall keep all detonators issued to them until about to be used in a securely locked case or box, separate from any other explosive.

In the case of a shaft being sunk from the surface, it shall not be deemed a contravention of this section if the primers for charges are fitted with detonators on the surface before being taken into the shaft, provided the primers are so fitted in a workshop established under Sec. 47 of the Explosives Act, 1875, and are only taken into the shaft immediately before use by the shot-firer or other authorised person and in a thick felt bag or other receptacle sufficient to protect them from shock.

Application of Order.

5. Secs. 1, 2 and 3 of this Order shall not apply to mines of clay or stratified or nodular ironstone, nor shall they apply to shafts in course of being sunk from the surface, or deepened, or to drifts and other outlets being driven from the surface, except as provided by Sec. 1 of the Order.

Where a mine contains several separate seams this Order shall apply to each seam as if it were a separate mine.

Definitions. 6. In this order the term "permitted explosives" means such explosives as are named and defined in the first schedule hereto, and the term "permitted igniter-fuse" means such igniter-fuses as are named and defined in the second schedule hereto: provided that where the composition, quality or character of any explosive or any igniter-fuse is defined in such schedules, any article alleged to be such explosive or such igniter-fuse which differs therefrom in composition, quality, or character, whether by reason of deterioration or otherwise, shall not be deemed to be the explosive or igniter-fuse so defined; provided further that an owner, agent, or manager shall not be responsible for the composition, qualitity, or character of an explosive or igniter-fuse, if he shows that he has in good faith obtained a written certificate from the maker of the explosive or igniter-fuse that it complies with the terms of the schedule, and that he has taken all reasonable means to prevent deterioration of the explosive or igniter-fuse while stored.

The term "road" includes all roads of any description extending from the shaft or outlet to within 10 yards of the coal face.

The term "main haulage road" means a road which has been, or for the time being is, in use for moving trams by gravity or by steam or other mechanical power.

When a shot has missed fire, and electricity has not been used in attempting to fire it, a caution board or fence shall be fixed at least 10 yds. from the place on all sides, and no person shall then pass such board or fence without the permission of the Manager, Under-Manager or Deputy.

132.—What Regulations are desirable

(*a*) **For the Protection of Shot-firers;**

(*b*) **To Prevent Accidents from Electrical Hang Fires;**

(*c*) **To Prevent Accidents through boring into or striking old Charges;**

(*d*) **For recovery of miss-fire Charges; and**

(*e*) **To Prevent Blown-out Shots.**

The following Instructions are issued by the Author to the officials and workmen under his control:—

INSTRUCTIONS TO SHOT-FIRERS.

1. Shot-firers are required, under the C.M.R.A., to make themselves familiar and to act in accordance with the C.M.R.A., 1887 and 1896, and the Explosives in Coal Mines Order of 1897.

2. The shot-firing cable shall not be less than 30 yds. in length (or as much longer as may be necessary to place the operator beyond reach of danger) and shall be effectively insulated.

3. The shot-firer shall examine his place of refuge and assure himself that he is adequately protected from danger before firing a charge.

4. A missed shot shall not be drawn or otherwise interfered with, nor shall it be approached until after the expiration of five minutes from the time of disconnecting the exploder. If the charge cannot be wedged down safely, a fresh hole shall be drilled parallel with the missed-fire charge at a distance not less than 12 in.

5. Holes for blowing down missed-fire shots shall be put in by the same men who bored the previous holes, and shall be fired by the same shot firer.

6. The shot firer shall, before firing a new charge, attach the missed-shot wires also to the firing cable by means of wire or cord, to aid in recovering the missed shot. Immediately after firing he shall search for the missed fire charge, and until he finds it, or is satisfied that it has been exploded by the second shot, he shall allow no person to interfere with the material.

7. When searching for an unexploded charge in material blown down, great care shall be taken that the detonator be not struck with pick or other tools.

8. Shot firers shall see that mineral containing or supposed to contain any portion of an unexploded charge shall, if the explosive is not recoverable, be securely packed in the goaf. Whenever possible miss-fire detonators and explosives shall be recovered and returned to the under-manager.

9. Explosives shall not, without special permission, be used for breaking in fast ends.

10. Shot holes shall be of just sufficient diameter to pass the cartridges in use, and they shall be drilled at such an angle that they do not directly face the air current.

11. Detonators without a charge shall not be fired in the mine.

12. Shot firers shall make a daily report in the book provided for that purpose, and shall also specially report in writing to the Under-Manager every case of missed-fire shot or other unusual occurrence.

APPENDICES.

NOTE TO APPENDICES I. AND II.

The Second Report of the Royal Commission on Mines having been published during the printing of "The Shot-Firer's Guide," an abstract has been made from the Summary of Main Conclusions relating to Shot-firing in Appendix I., and a description of the "Garforth" gas detector therein referred to is reproduced in Appendix II.

APPENDIX I.

SUMMARY OF MAIN CONCLUSIONS RELATING TO SHOT-FIRING.

(From the Second Report of the Royal Commission on Mines.*)

1. The various regulations in force in regard to shot-firing are very complicated and require consolidation. So far as practicable, all the regulations as to shot-firing should be issued as one code, and copies should be supplied to shot-firers. (Page 113.)

2. *Main Haulage Roads and Intakes.*—Owing to the serious accidents which have been caused by shot-firing on main haulage roads, the firing of such shots should be confined within as narrow limits as possible, and subjected to the strictest precautions. We make a number of recommendations on this point. (Page 116.)

3. *Shot-firing at or near the Working Face* —"Ripping" shots should be fired when as few men as possible are in the mine, and, if practicable, between the shifts. (Page 119.)

* Cd. 4,820, 1909.

4. As a substitute for watering before firing a shot, it is suggested that further experiments should be made as to the effectiveness of soda and wood pulp tamping. (Page 120.)

5. The rules as to testing for gas before shot-firing should be more stringent, and some appliance similar to the "Garforth" gas detector should be brought into general use. (Page 120.)

6. *General Precautions as to Shot-firing.*—Persons appointed as shot-firers should be examined as to their abilities to test for gas in the same way as firemen and deputies. (Page 121.)

7. Permitted explosives should be fired only by electricity. Other explosives should be fired either by electricity or proper safety fuse, and the use of straws or squibs should be prohibited. (Page 122.)

8. Where permitted explosives are required to be used, the shot hole should be charged and stemmed by or under the personal supervision of the shot-firer. (Page 124.)

9. Firing shots in the "fast" should be prohibited. The Explosives Order should require the hole to be properly placed as well as properly drilled. The standardisation of the size of the cartridge of explosives would be a great advantage. (Pages 124, 125.)

10. The question of defining more clearly the amount of stemming required and of fixing some proportion between the amount of the explosive and the length of stemming should be considered. (Pages 125, 126.)

11. There should be a uniform rule dealing with miss-fired shots which should provide, *inter alia*, that no one should approach such shot except after a sufficient interval. The use of proper "warming pans" for explosives containing nitroglycerine should be made compulsory. (Pages 126, 127.)

12. *Testing of Explosives.*—The revision of the Government test on the lines recommended by the Bobbinite Committee should be taken in hand. (Page 128.)

13. *Storage of Explosives.*—Explosives should be provided by the owners and stored at the colliery. (Pages 128, 129.)

Appendix II.

(c) TESTING FOR GAS.*

The greatest risk in shot-firing at or near the working face lies in the possibility of gas being present. We think it should be made clear in the rules that no shot must be fired in any circumstances where any indication of a "cap" can be seen on the reduced flame of a safety lamp, and that the place of firing should be carefully tested within a radius of 20 yds. before the shot is fired. Having regard to the fact that gas may lurk in fissures in the roof or sides which it is impossible to detect with any form of safety lamp, we think that some appliance similar to the "gas detector" designed by Mr. W. E. Garforth should be brought into general use.

For the information of managers who are not already familiar with the use of this "gas detector," we are able to reproduce the attached illustrations (Figs. 74, 75, 76, pp. 181-2), with which Mr. Garforth has kindly furnished us, not only of the "gas detector," but also of a safety lamp specially designed by him for the purpose of detecting firedamp. Mr. Garforth describes the arrangement as follows :—

"The detachable indiarubber ball is inserted into a break in the roof and, after the air contained in it has been expelled by pressure of the hand, it is allowed to expand, whereupon it becomes filled with a sample of the suspected atmosphere. The contents of the ball are then introduced on to the flame of the lamp through a safety gauze-protected pipe, which the brass nozzle of the ball exactly fits. If firedamp be present it is shown by an elongation of the lamp flame, and by a blue cap burning at the top of the gauze pipe, which latter is fitted with a small spring valve raised when desired by the serrated brass nozzle of the ball.

"To indicate a low percentage of firedamp when found in the main return airways, working places or other parts of a mine, the lamp is fitted with an extinguisher which is made to surround the wick tube, consequently, when the extinguisher

* From the Second Report of the Royal Commission on Mines, p. 121. Cd. 4.820, 1909.

is raised or lowered by a screw actuated by the hand of the official from the bottom of the lamp, the flame of the lamp can be altered from a large to a small or non-luminous one. By this method, and the addition of a regulating nut, a more delicate adjustment of a non-luminous flame is obtained with less liability to extinguish the light, and much quicker than by the ordinary 'pricker' arrangement. Attached to the extinguisher and moved with it is a white enamelled graduated standard which is placed immediately behind the flame, whereby the height of the cap or halo of a non-luminous firedamp flame may be measured. The lamp is also fitted with a magnifying glass, so arranged that it can be used or not as desired without obstructing the light of the lamp. It also enables a non-luminous flame to be more easily seen, and, when required, throws a brighter light on the roof or obscure places.

"The improvements herein described do not interfere with the tin shield of the lamp, which 20 years' experience has proved to be the safest arrangement in resisting an explosive current travelling at a high velocity.

"As the method of detecting firedamp by means of the indiarubber ball has been in daily use for the past 24 years, it is interesting to know that the opinion of more than 100 colliery officials is :—

"(*a*) That the ball enables a deputy, or fire-trier, to discover firedamp which cannot be found by the ordinary tin shield lamp, which for reasons well known is not as sensitive to detect gas as the 'Davy.'

"(*b*) That it is safer to bring a suspected atmosphere to the lamp by means of the ball than to introduce a lamp into gas.

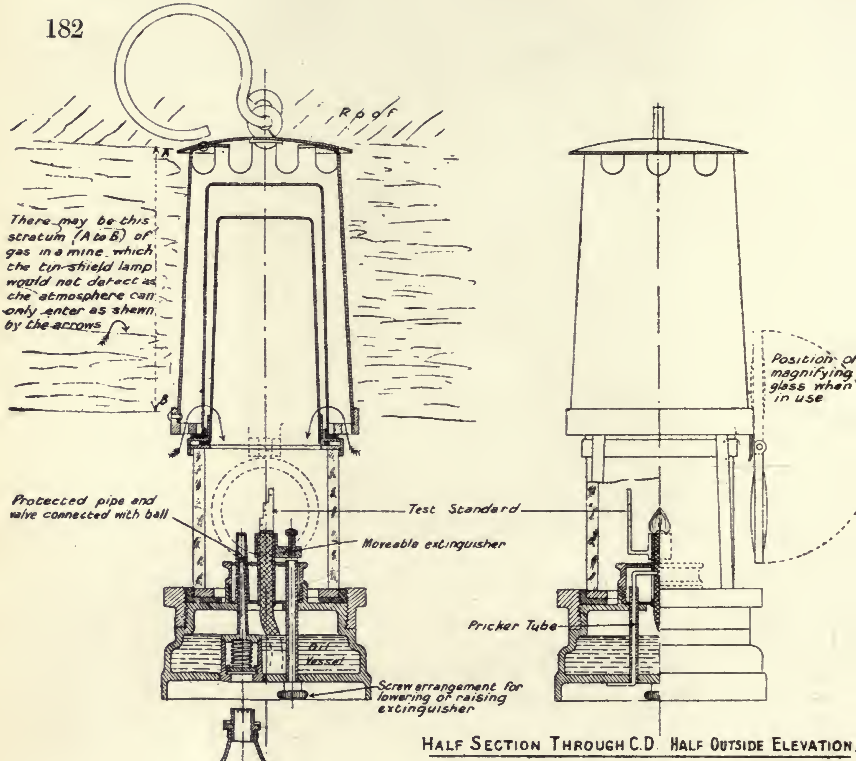
"(*c*) That firedamp when discovered can be safely and promptly dealt with by fixing the necessary sheets to render it harmless, which precautions are not taken when the tin shield lamp has failed to indicate gas.

"(*d*) That there is not the same risk of the lamp being extinguished when using the ball as when testing in the ordinary way, which is important, especially if the official is 1½ miles from the shaft where workmen may be awaiting his instructions before they can proceed to work.

"(*e*) More tests can be made in a given time with the ball, consequently an official is assisted in his work by knowing the precise conditions of the coal face, return airways, &c."

FIG. 74.—INSERTING THE INDIARUBBER BAG INTO A BREAK IN THE ROOF TO COLLECT A SAMPLE OF THE SUSPECTED ATMOSPHERE.

FIG. 75.—FORCING THE COLLECTED ATMOSPHERE OR FIREDAMP ON TO THE FLAME OF THE LAMP LEVEL WITH THE EYE.



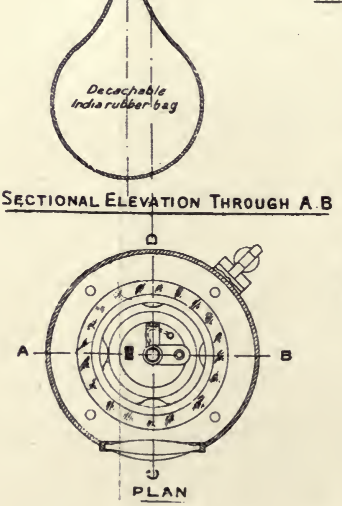


FIG. 76.—THE GARFORTH FIREDAMP DETECTOR LAMP.

With detachable indiarubber bag, movable tinguisher with screw adjustment to produce a luminous flame, graduated standard and magnif glass.

APPENDIX III.

BRITISH COAL DUST EXPERIMENTS AT ALTOFTS.

The account of the British coal dust experiments which was given in Questions 107-8 in the text, recorded the results which had been obtained to August, 1908. The Mining Association of Great Britain have issued a report (July 30th, 1909) during the printing of " The Shot Firer's Guide," which records the important work which has been carried out during the year. They state that their main object was to demonstrate to as many as possible of officials and others connected with the practical working of coal mines the fact that coal dust, without the presence of any inflammable gas, formed an explosive mixture with air, and that if this mixture were ignited by any means, such as a blown-out shot, the destructive effects were equal to, if not greater than, those produced in a firedamp explosion.

In addition, trial was made on a practical scale of the various remedies or preventives that have been suggested. Upwards of 600 people witnessed the explosions, which were successfully demonstrated in 38 cases out of 41.

Many of those who came to witness were sceptical as to the inflammability and explosive force of coal dust when mixed with air, without the presence of firedamp, but in no single instance was any room left for doubt after the length of flame and the destructive effects had been demonstrated to them.

The gallery in which the experiments are made is constructed of boiler shells 7 ft. 6 in. and 6 ft. in diameter, and in a few of the experiments of 1908 attained a length of 1,083 ft. For the 1909 experiments, the total length is 895 ft. It is divided into two parts—a main intake, in which the actual experimental explosion is produced, 7 ft. 6 in. in diameter and 600 ft. long, and a return airway 6 ft. in diameter and 295 ft. long.

This return airway leads to a fan which produces a ventilating current such as is commonly met with in a mine, provided with safety valves to relieve the pressure set up by the explosion.

In order to render the conditions as nearly alike as possible in each experiment, the requisite amount of dust is ground from nut coal previous to each explosion. The size of the particles is based upon samples taken from the highest parts of roadways in the mine. After being ground it is spread on narrow shelves running on both sides of the gallery in imitation of the ledges and crevices presented by the packs, &c., of an underground roadway (*see* view of interior).

FIG. 77.—VIEW OF INTERIOR OF GALLERY.

The amount of coal dust agreed upon having been spread, it is raised in suspension in the air-current either by the firing of a small cannon, or by the merely mechanical action of the air-current, and whilst in suspension it is ignited by the flame from a large cannon which is charged with blasting powder, and represents in its effect a blown-out shot, such as was the cause of the majority of the great colliery disasters, including the explosion at the Altofts Collieries in 1886.

The experiments involving the use of remedial measures are similar in nature. The explosion of the coal dust is obtained in precisely the same way, but the disposition of the lengths strewn by coal dust is so arranged that the flame of the explosion encounters in its passage zones of watering, stone dust, carbonate dust, or lengths of gallery clear of dust, called dustless zones.

The effects of such measures in checking the velocity and reducing the pressure of the explosion are recorded automatically by means of instruments, many of which have been specially designed for the purpose.

The Altofts gallery is on a natural scale and is the largest, both in sectional area and in length, that has ever been used either in this country or abroad for such work.

The experiments carried out during the present year (1909) have been of a scientific character, and form part of a series undertaken with the idea of investigating the whole nature of the explosions. The experience gained during this period has served to reinforce the hope that in stone dust an effective remedy has been secured.

The following experiments indicate clearly the effect of exploding coal dust (1) alone, (2) adjoining a dustless zone, and (3) adjoining a stone dust zone.

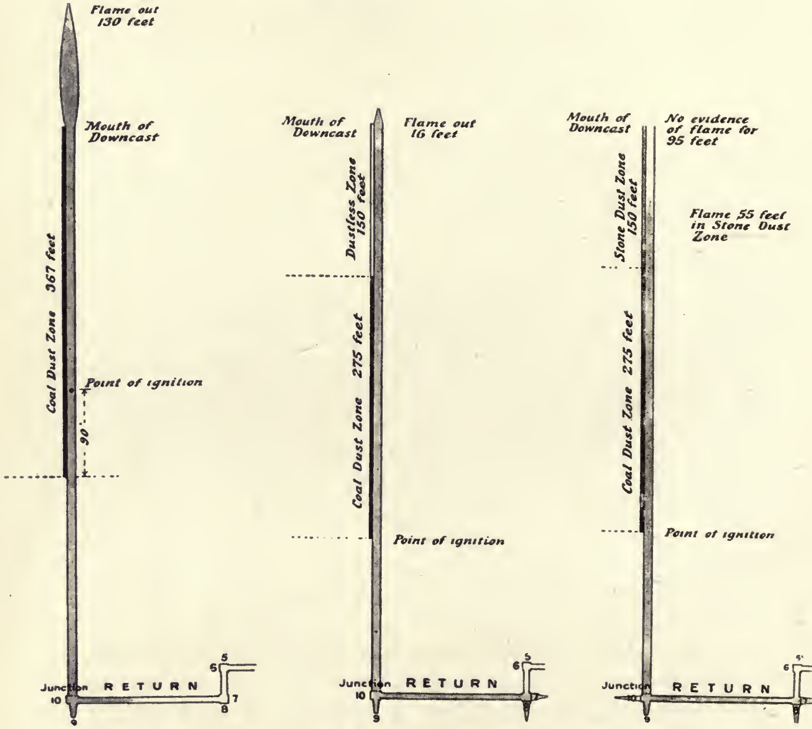
In the first (experiment No. 61, July 17th, 1909), a length of 367 ft. of the main intake was spread with coal dust, 1 lb. being used per running foot of the gallery, or per 41 cubic ft. of gallery space.

On exploding the coal dust a flame about 170 ft. long shot out of the open end of the tube, and there were manifest signs of the setting up of great internal pressure.

In the second (experiment No. 55, July 2, 1909), a similar weight of coal dust was exploded, but this time the explosive force was caused to pass through a dustless zone 150 ft. in length. By means of recording instruments, which are attached to the gallery, it was found that the pressure rapidly attained a maximum of 113 lb. per square inch, greater by over 68 lb. than that which obtained at the end of the coal dust zone. This is explained by the fact that, in the initial stage of the explosion, dust is driven in front of the actual explosion wave, so that the "dustless" zone is in reality non-existent.

Turning now to experiment No. 57 (July 8th, 1909), in which a stone dust area takes the place of that which in the previously described experiment was "dustless," it was found that the pressure, instead of rising, decreased, and died away as soon as it could be wholly released at the mouth of the gallery.

The plans given in Fig. 78 illustrate diagrammatically the results of this set of experiments.



EXPERIMENT No. 61. (JULY 17, 1909). EXPERIMENT No. 55. (JULY 2, 1909). EXPERIMENT No. 57. (JULY 8, 1909).

Length of main intake, 600 ft.; sectional area, 41 sq. ft. Length of return, 295 ft.; sectional area, 28 sq. ft. Numbers indicate position of safety valves.

FIG. 78.

Later experiments have tended to confirm the tests previously made, and it appears to have been satisfactorily proved that a certain class of stone dust suitably applied does arrest the flame of an explosion.

APPENDIX IV.

EXAMINATION QUESTIONS RELATING TO SHOT-FIRING.

(i.) Describe the safety-fuse commonly employed and state how it is used.

(ii.) What is blasting gelatine, and how is it fired ?

(iii.) Explain the construction of some electric fuses and their advantages as compared with ordinary safety fuse.

(iv.) Give some rules for ensuring safety in blasting or "shot-firing," as far as possible.

(v.) Draw a set of hand tools for boring holes for blasting and for charging them. Explain how the drills are sharpened.

(vi.) Describe the nature and composition of some of the explosives placed upon the "Permitted List." What is the test which has to be passed before an explosive is placed upon this list ?

(Board of Education, Principles of Mining, 1901.)

(vii.) A tunnel, which is used as a haulage road and also for the main return airway, and which is dry and dusty, requires to be enlarged. When should the shots be fired ? Give in your own words the rules applying here. What explosive would you use, and why ?

(viii.) What precautions must be taken before and after firing a shot in a sinking pit ?

(Manchester and Ireland District, 1902.)

(ix.) What is the chemical composition of

(*a*) Air ;

(*b*) Fire-damp ;

(*c*) Black-damp ?

(x.) What is the most explosive mixture of fire-damp and air? Show what gases would be formed by an explosion of such a mixture, giving the relative proportions of the resultant gases.

(xi.) What precautions would you take to prevent explosions of coal dust in a mine?

(xii.) State the most important requirements of the Coal Mines Regulation Act as to shot-firing in a fiery mine. What are the requirements as to detonators? What other precautions would you enforce? What do you understand by "permitted explosives"?

(Liverpool and North Wales District, 1902.)

(xiii.) When a shot misses fire, what precautions are to be taken? Give in your own words the General and Special Rules applying thereto.

(Manchester and Ireland District, 1903.)

(xiv.) State shortly the requirements of the Coal Mines Regulation Acts as to explosives in reference to

(*a*) Quantity to be taken at a time;
(*b*) Stemming and blasting;
(*c*) Missed shots;
(*d*) When locked safety lamps are used or the mine is dry and dusty;
(*e*) When inflammable gas has been reported to be present.

(xv.) Why is coal dust a source of danger? In what part of the mine would you be most likely to find it? What arrangement should you adopt for keeping down dust?

(xvi.) What are the requirements of the Coal Mines Acts where coal dust is existing?

(xvii.) What is the danger arising from a blown-out shot, and how is it caused?

(xviii.) When are permitted explosives only to be used?

(xix.) Name a few of these permitted explosives, and name their constituents.

(xx.) What are the requirements of the Coal Mines Regulation Acts as to blasting?

(xxi.) Name as many as you can of the various explosives used in mining, and state the ingredients of which they are composed.

(xxii.) Name the circumstances under which you consider a high explosive preferable to ordinary gunpowder.

(xxiii.) Are you acquainted with the last Explosives Order? If so, state shortly what it is.

(xxiv.) What precautions would you adopt for the safety of the men where shots are fired simultaneously? How would you deal with electric light and shot-firing cables when shot-firing at a depth of more than 600 yards from the surface? **(Stafford District, 1904.)**

(xxv.) What are the most important requirements of the Coal Mines Regulation Act as to shot-firing in a fiery mine? And what are the special rules (1902) that apply to shot-firing? What other precautions would you adopt?

(xxvi.) In firing "roofing down" shots and coal shots, what precautions would you instruct your shot-firer to take in respect to the use of the battery and cable, and also as to his position when firing?

(Liverpool and North Wales District, 1904.)

(xxvii.) In what proportions are mixtures of pure fire-damp and pure air explosive; and what effect has the presence of coal dust upon such mixtures?

(Newcastle District, 1904.)

(xxviii.) State the requirement of the Acts and Special Rules in regard to shot-firing on main haulage roads and main returns.

(xxix.) What percentage of fire-damp when mixed with air is necessary

(*a*) To show a faint cap;
(*b*) To readily explode;
(*c*) To be at the most explosive point?

(Manchester and Ireland District, 1904.)

(xxx.) Give the names of the permitted explosives with which you are practically acquainted. State which you prefer for use in coal and hard rock respectively, and why. What class of explosives are liable to freeze in winter, and how should they be dealt with ?

(xxxi.) Under what circumstances does coal dust become a source of danger in mines ? Where do you find it mainly; and what precautions would you take in a fiery mine to minimise the danger ?

(Manchester and Ireland District, 1905.)

(xxxii.) What do you consider the best method of firing shots: first, in a fiery mine; second, in a mine where there is no gas ?

(xxxiii.) What are the provisions of the Act with reference to the use of explosives on main haulage roads ?

(Newcastle District, No. 3, 1905.)

(xxxiv.) Why is coal dust dangerous in a dry mine which is worked with safety lamps ?

(xxxv.) In what circumstances is it necessary that only explosives on the Permitted List be used underground ? Mention the precautions you would take before using them in order to ensure safety.

(xxxvi.) What special precautions have to be taken in mines worked by safety lamps when using electricity for firing shots ? Give reasons for the need of these precautions.

(East Scotland District, 1906.)

(xxxvii.) Describe the various gases found in coal mines. Give their chemical composition and the means of detecting their presence. Describe the part played by coal dust in an explosion.

What are the various sources from which it is got, and what means would you take to render its presence harmless ?

(West Scotland District, No. 2, 1906.)

(xxxviii.) Quote General Rule 12, section (*f*), with reference to shot-firing where safety lamps are used.

General Rule 12 section (*d*) says: "Nor shall coal or coal dust be used for tamping." How has this portion of Rule 12 been amended? Give reasons for the amendment.

(xxxix.) In what circumstances are the use of explosives permitted in main haulage roads?

(Newcastle District, 1906.)

(xl.) Where are accumulations of coal dust most likely to be found in collieries underground, and what are the dangers arising therefrom?

Describe how you would deal with coal dust so as to reduce the risk of accidents.

(xli.) What are the chief differences between the nitrate of ammonium and the nitro-glycerine classes of explosives? Give examples of two of each with their respective compositions, and describe the special precautions which must be taken with each class.

(Liverpool and North Wales District, 1906.)

(xlii.) What precautions are required by the Coal Mines Act and Special Rules in the requirements for shot-firing and tamping?

(xliii.) Explain why dust in mines is understood to be a danger, and describe the best means of laying the dust, and the several methods you are acquainted with for dealing with the dust.

(xliv.) Of what is fire-damp composed, and under what conditions will it explode? Give the chemical equation showing the changes which take place in an explosion of fire-damp and air, and also give the names and nature of the resulting mixture, with relative volumes.

(xlv.) What precautions would you adopt where gas is given off and known to exist in a cavity above the main haulage road?

(Southern District, 1906.)

(xlvi.) What are the provisions in the Electricity Rules regulating shot-firing from a power or electric light circuit?

(xlvii.) Four shots in a sinking pit are ready for firing. What are the objections to firing them

(*a*) By tape fuse;
(*b*) By electricity?

How can these objections be overcome?

(xlviii.) What are the provisions of the Coal Mines Regulation Acts and the Explosives in Coal Mines Order, 1899, respecting the care of explosives underground; the charging and stemming of shots; and the storage, custody and use of detonators above and below ground?

(xlix.) Describe in detail the operation of charging, stemming and firing a shot where there is no coal dust, showing how you would deal with a missfire and giving the precautions you would take throughout.

(Manchester and Ireland District, 1906.)

(l.) Where are accumulations of coal dust most likely to be found in collieries underground, and what are the dangers arising therefrom? Describe how you would deal with coal dust so as to reduce the risk of accidents.

(li.) What are the chief differences between the nitrate of ammonium and the nitro-glycerine classes of explosives? Give examples of two of each with their respective compositions, and describe the special precautions which must be taken with each class.

(Liverpool and North Wales District, 1906.)

(lii.) What are the rules regulating the use of explosives in coal mines? Give a list of the authorised explosives and any details with which you may be acquainted connected with the efficiency in use of any one of them.

(Staffordshire District, 1906.)

(liii.) Why is it a dangerous practice to test a shot-firing cable by holding the wires to the metallic cover of a safety lamp ?

(Newcastle District, 1907.)

(liv.) Describe any means that may be adopted to supersede blasting in mines.

(lv.) Why should a place be visited soon after firing a shot ?

(Southern District, 1907.)

(lvi.) What must you do before re-entering a place when a shot has missed fire

(*a*) Where fuse is used ; and

(*b*) Where electricity is used ?

(lvii.) Do you consider that the rule for miss-shots where electricity is the firing medium requires alteration ? And if so, in what way ?

(lviii.) A mixture of air and fire-damp at the highest explosive point is passing along an airway 5 ft. 8 in. by 4 ft. 6 in. at a veloc ty of 460 ft. per minute. What quantity of fresh air must be added so that you cannot detect the gas on the flame of an ordinary safety lamp ?

(Manchester and Ireland District, 1907.)

(lix.) What is fire-damp, and what means have you of testing for it to ascertain its percentage in the air ?

(lx.) How can the safety lamp be used as a fire-damp detector ? Describe some lamps arranged for this use.

(lxi.) What precautions are required by law to be taken in the firing of shots by electricity underground ? Say in what circumstances it is permissible to use ordinary powder, and whether you prefer it to any permitted explosive you know of in the case of

(*a*) Coal getting ;

(*b*) Rock heading.

(lxii.) Give some definition of coal dusts as between, say, a very dangerous and a safe form. To what extent, if any, do you consider precautions are necessary beyond those already enforced by law?

What precautions are necessary in firing shots in main roads. Why should such operation be dangerous?

(lxiii.) Do you consider all collieries liable to coal dust explosions? If not, point out why some are exempt; name the rules which regulate the firing of shots in dry and dusty mines.

(lxiv.) What explosives have you had experience of, and what are the regulations in force at any colliery with which you are acquainted in addition to those enforced by law?

(lxv.) Name two of the most important rules relating to firing shots.

(Stafford District, 1907.)

(lxvi.) Describe in detail the arrangements you would make for firing shots by electricity in a mine worked with safety lamps.

(lxvii.) Describe the arrangements you would make for storing and distributing explosives, and what regulations you would make for the safe keeping of unused explosives in the men's possession after their day's work was done.

(West Scotland District, 1908.)

(lxviii.) Describe the operation of charging and firing a round of shots at the bottom of a sinking shaft, and say what special precautions you would take as to signalling, &c. Where have the "primers" for sinking shots to be prepared?

(lxix.) Previous to firing a shot, what precautions would you take to prevent having a blown-out shot? What are the special rules to be observed in the case of a "missed shot"?

(Liverpool and North Wales District, 1908.)

(lxx.) Mention some of the more important "permitted explosives" contained in the Coal Mines Order of December, 17 1906. What are the rules relative to detonators contained in that Order?

(lxxi.) How do explosives vary as regards

(*a*) Temperature of ignition;

(*b*) Maximum flame temperature?

and what methods have been employed to reduce the latter temperature artificially in safety explosives?

(lxxii.) Detail carefully the provisions of the Metalliferous Mines Regulations Acts as to explosives and blasting.

(lxxiii.) Give roughly the composition of some of the more important explosives used in mining.

(Assistant Inspectorship of Mines Examination, February, 1908.)

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1. Name the exceptions to the application of the Order.
2. What are the rules as to the use of explosives in cartridges?
3. Give the clause relating to charging, drilling and stemming.
4. Define "permitted explosives," "permitted igniter fuse," "road" and "main haulage road."
5. State the conditions regulating the use of detonators.
6. Give the rules regulating the use of electrical firing apparatus.
7. What precautions are required to be taken when two or more shots are fired in the same place?
8. How is the use of fuse regulated?
9. What are the rules regulating the qualifications and appointment of shot-firers?
10. Under what circumstances are certain explosives (*a*) absolutely prohibited, and (*b*) conditionally prohibited?
11. How are detonators permitted to be used in sinking shafts?
12. State the rule as to watering in the neighbourhood of a shot.
13. State the rule as to withdrawal of men during shot-firing in main haulage roads and intakes

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Cooper—*See* "THE ELECTRICIAN" PRIMERS, page 11.

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