GAS AND DUST GALLERY NO. 1, PITTSBURG TESTING STATION.

DEPARTMENT OF THE INTERIOR
UNITED STATES GEOLOGICAL SURVEY
GEORGE OTIS SMITH, DIRECTOR

BULLETIN 423

A PRIMER ON EXPLOSIVES FOR COAL MINERS

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AND

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WASHINGTON
GOVERNMENT PRINTING OFFICE
1909

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ILLUSTRATIONS.

NOTE.

This bulletin is issued and distributed in the hope that it may lessen the accidents caused by the improper use of explosives in mining operations. The Geological Survey will be glad to receive any suggestions as to additions or other changes which, in the opinion of readers, would increase the usefulness of this primer in accomplishing this purpose.

INTRODUCTION.

By J. A. Holmes.

Of the common causes of the larger mine accidents, such as falls of roof and coal, gas and dust explosions, mine fires, and the misuse of explosives, all of which are often closely related, each must be studied and fought in a manner peculiar to itself. The last-mentioned, the misuse of black powder and other explosives, is sometimes considered the least important of these causes of mine accidents; but its importance is much greater than the statistics indicate, for the reason that the misuse of explosives is the true cause of many of the fatal mine fires, gas or dust explosions, and falls of roof that are credited to other causes.

Both the quantity of explosives used and the number of purposes to which they are applied are increasing. They are now made at about 150 plants, in different parts of the United States, and the product of a single year is estimated at nearly 500,000,000 pounds. Nothing in all this material is a safe or "safety" explosive when in the hands of a careless or ignorant person; and this is true whether considered in connection with the shipment or the use of these explosives. In addition to the large losses of life and property resulting from an improper use of explosives in mining, the recent statistics of the railway bureau for the safe transportation of explosives have shown more than 400 persons killed or injured and over $3,000,000 worth of property destroyed by explosives in transit by rail. The fact that three years of cooperative effort under the wise supervision of this bureau has reduced these losses to almost nothing encourages the hope that similar cooperative effort may likewise greatly lessen losses of life and property from the use of explosives in mining.

The additions to the large death roll of our mines make a recurring appeal to the public for fair treatment of the coal-mining industry, and to the miner and the manager that they join in every possible effort for greater safety. It may never be possible under conditions such as exist to-day to prevent mine accidents entirely. Little can be accomplished in that direction by either the operators or the miners working alone, but experience in all countries shows that through the hearty determined cooperation of both the accidents may be greatly reduced. This will require wise laws and regulations based on fact and experience, and the strictest possible discipline.

The accidents resulting from the improper use of explosives in mining can be most certainly prevented (1) through the use of the best and safest explosives; (2) through the handling and firing of these explosives in the safest manner by carefully selected and trained men; and (3) through the strict and competent oversight of these men.

This little book on explosives is published in the hope that it may aid in preventing such accidents. The aim has been to tell what explosives are and how they should be handled, with a view to greater safety; and to do this in language free of unnecessary technicalities. It has been prepared by Charles E. Munroe, consulting explosives expert, and Clarence Hall, explosives engineer of the United States Geological Survey. It has been revised in the light of suggestions made by the mining engineers associated with the Survey, by several mine managers, by experts associated with the manufacture of explosives, and by Col. B. W. Dunn, chief of the bureau for the safe transportation of explosives, who has also kindly added a brief chapter on the transportation of explosives.

Much of the information in this primer has been obtained from experiments conducted at the mine-accidents station of the United States Geological Survey at Pittsburg, authorized by Congress in May, 1908, for investigations as to the "causes of mine explosions." These investigations have shown the recent development of a new type of short-flame explosives, which can be used with greater safety than black powder in mines where there is dangerous gas or inflammable dust, because the flame from the explosion of black powder lasts from 2,500 to 3,500 times as long as does the flame from these newer explosives, and is therefore more likely to ignite the gas or dust in such mines.

Lists of permissible explosives were issued by the Geological Survey on May 15 and October 1 of the present year, and with these lists was printed a statement of the conditions under which the explosives were selected from a larger number offered for examination. These lists comprise 31 explosives. There are also in course of publication and soon to be issued bulletins dealing with other phases of the subject, such as methods and results of using permissible explosives in coal mining, the results of tests of explosives, and the dust problem in coal mining.

A PRIMER ON EXPLOSIVES FOR COAL MINERS.

By C. E. Munroe and Clarence Hall.

COMBUSTION AND EXPLOSION.

Fire.

There is probably no activity of nature with which man is better acquainted or has been longer acquainted than with fire, of which he has made use from the earliest days for warming his body, cooking his food, giving him light, and in more recent times for breaking down rock, for making steam, and for other purposes. He has observed that a great number of substances can be burned, such as wood, charcoal, coal, sulphur, phosphorus, magnesium, zinc, oil and gas in their many varieties, and many others, and he has made use of them to produce heat and light. He has noticed that when wood is burned in large sticks it is difficult to start the fire, and that where there are but a few large sticks the fire burns but slowly. When the wood is cut into kindlings and these are heaped together, they burn more rapidly. When the kindlings are cut into shavings and these are piled together, they burn still more rapidly; and when the wood is cut into dust by means of a saw and this dust is suspended in the air and set on fire, it burns with explosive rapidity.

Combustible substances.

The same thing is found to be true of the other substances that burn under ordinary circumstances and are therefore called combustible. That is, the more finely divided they are and the more intimately this finely divided material is mixed with the air, the more rapid is the burning or combustion. This intimate mixture with the air is best attained with gases such as marsh gas (the fire damp found in mines), coal gas such as is used for lighting, and acetylene, or with vapors such as those from gasoline; and when these are thus intimately mixed with the air the combustion goes on so rapidly that it takes the form of an explosion. Although an explosion is thus easily produced by mixing gas or vapors and air in the right proportions, explosions may also be obtained by mixing combustible dusts with the air in the right proportions and igniting them; and therefore we are not surprised to hear that explosions have been occasioned by mixtures of sawdust or flour dust or starch or sugar or soap or coal dust with the

Explosion.

Dust explosions.

air. Many explosions thus produced are very violent, and destroy life and property. (See Pls. II and III.)

Air necessary to ordinary combustion.

In each of the kinds of combustion or explosion that have been spoken of the combustible substance is mixed with air, and that the presence of air is necessary for the combustion is proved by the fact that when we cut off the air from contact with a burning body the fire goes out, or, as we say, we have smothered the fire.

Oxygen of the air necessary for combustion.

The reason for this has been found in the nature of one of the several different substances that the air is composed of. This is the gas named oxygen, which is about one-fifth of the whole volume of the air. It is possible to separate this oxygen from the air, and when this has been done and burning bodies are brought into contact with this separated oxygen it is found that they burn much more rapidly than in air, and that the combustion is much more brilliant. By repeated experiment it has been proved that all ordinary combustion is caused by the combination of the combustible substance with this oxygen of the atmosphere. Air deprived of its oxygen will not support combustion or life.

Oxygen from saltpeter.

In view of these facts, and in view, further, of the fact that there are other substances in nature besides air that contain oxygen and will give up this oxygen to combustible substances, it would seem probable that combustion could be brought about through the aid of such oxygen-containing bodies; and this was long ago proved to be true. One of the first, if not the first, of such bodies that became known to man is saltpeter, also called niter, or potassium nitrate, which, because it occurs as a white efflorescence like frost on the surface of the soil in India, has been called India saltpeter, although it has been found to some extent in many parts of the world.

Saltpeter supports combustion.

If solid saltpeter in the dry condition is mixed quite thoroughly with a solid combustible substance, such as charcoal, the mixture burns easily when once it is ignited. The advantage of such a mixture is that the oxygen which is to support the combustion is in close contact with the charcoal which is to be burned, and that, therefore, this substance or mixture can be ignited and will burn without contact with the air, and will so continue to burn until the charcoal is completely consumed. As a result of the burning of the charcoal or carbon with the oxygen of the saltpeter a gas is formed. As another result of the burning of this mixture of charcoal and saltpeter heat is produced, and this heat warms up the gas, so that if it is unconfined its volume becomes greatly expanded, and if it is confined it exerts pressure

Charcoal with saltpeter produces heat and gas.

EXPLOSION FROM FLOUR IN MILLS AT MINNEAPOLIS IN 1878.

and does work. Hence, if such a mixture be burned in the bore hole of a rock, it may break down the rock, or in the barrel of a gun it will drive out the bullet.

It is found, however, that it is not easy to ignite such a mixture of charcoal and saltpeter, even when mixed in the best possible way, and to overcome this difficulty use is made of another substance that ignites easily, one which on burning gives out heat enough to ignite the mixture of charcoal and saltpeter. This substance is sulphur, or brimstone, such as has been used in the past for the tips of sulphur or brimstone matches, for which the same object of easy ignition was sought. So eventually the mixture has been made of charcoal and saltpeter and sulphur, which are finely ground and closely mixed and then formed into grains, and such a mixture is called gunpowder.

Sulphur is added to make the mixture ignite easily.

As has been pointed out, it is simple combustion that takes place when such mixtures are set afire, but on account of the thoroughness of the mixing, the proportions in which the different substances are mixed, and the way in which the material is finally made into grains, this combustion may proceed so rapidly that there is an explosion, which is powerful because the solid mixture, occupying a very small space, gives on combustion a large volume of highly heated gases.

About 1821 there was discovered in the desert regions of Peru and Chile another saltpeter, sodium nitrate, which has come to be known by the name of Chile saltpeter. Like the India saltpeter, potassium nitrate, it contains oxygen, and it will give up its oxygen to combustible substances with ease at a relatively low temperature. Hence a mixture of it with charcoal (known also as carbon) and sulphur makes a body similar to that produced with the India saltpeter, and since 1857 such a mixture has been extensively used, especially in this country, for blasting in rock and in mines.

Chile saltpeter contains oxygen.

Besides the India and the Chile saltpeters, many other solid substances that contain oxygen and will give up their oxygen easily, on heating, to combustible substances have become known, and many of them have been tried in the formation of explosive mixtures. Though one or two of them are used to some extent, as will be shown further on, none are used so largely as the saltpeters.

Oxygen in other bodies.

It has also been found that we can get the oxygen out of the saltpeters in other ways than by heating an explosive mixture, as, for instance, by heating either the India or the Chile saltpeter in a proper manner with sulphuric acid, when we obtain from them nitric acid, which contains all of the oxygen originally in the saltpeters. It has further been

Nitric acid from saltpeter.

learned that when substances like cotton or starch or glycerin are treated with nitric acid in the proper way there are formed, from the cotton, gun cotton, or nitrocellulose, as it is also called; from the starch, nitrostarch; from the glycerin, nitroglycerin; and through this means the cotton, the starch, and the glycerin, which are all combustible substances, are converted into substances much more highly explosive and more powerful than mixtures made with the saltpeter and sulphur and combustible substances. In fact, such bodies can be made to explode by a shock such as is produced by a detonato or blasting cap when fired in contact with them, and the explosion is extremely rapid and very much more powerful than that of the saltpeter mixtures.

Putting oxygen into cotton, glycerin, etc.

It has also been found that by the action of alcohol upon nitric-acid solutions of metals, such as copper or silver or mercury, under proper precautions, substances may be formed which are still more sensitive and still more violent in their explosive effects than guncotton or nitroglycerin. The best known and the most widely used of these substances is fulminate of mercury. When dry, this substance is so sensitive that a very slight blow, very little friction, or a slight rise in temperature will cause it to explode, and on explosion it produces a shattering effect upon any substance with which it is in contact. Moreover, the character of its explosion is such that if but a small mass of it is exploded in proper contact with gun cotton or nitroglycerin or dynamite or other similar explosive, it will cause each of them to undergo a very violent explosion, which also will produce a shattering effect on the bodies with which they are in contact.

Sensitiveness and violence of fulminate of mercury.

From what has been said it will be seen that there are at least two classes of explosives. One class is the saltpeter mixtures, in which an explosion is brought about by simple combustion that proceeds rapidly and gives rise to a large volume of highly heated gases, though almost one-half of the mass remains as a solid residue. Explosives of this class exert a relatively slow pushing effect upon the substances with which they are in contact when they explode, and are called "low" explosives. In the other class are explosives of the character of gun cotton and nitroglycerin, which undergo explosion by being suddenly and wholly resolved into a large volume of highly heated gases, the change proceeding many times faster than the combustion that takes place in the saltpeter class of explosives. Because of their speed and power these explosives have a shattering effect upon the substances with which they are in contact, and are known as "high" explosives, and also sometimes as detonating explosives.

Low explosives.

High explosives.

EXPLOSION FROM COAL DUST IN GAS AND DUST GALLERY NO. 1, PITTSBURG TESTING STATION.

Every explosive, when exploded, exerts pressure in every direction. When laid on top of a rock and exploded, gunpowder and other low explosives do not affect the rock, because they explode so slowly that the gases formed can lift the air above them and escape; but dynamite, fulminate of mercury, and other high explosives, if laid upon brittle or soft rock and detonated, may shatter it, because they explode so quickly that the gases formed can not lift the large volume of air which confines them without pressing back forcibly against the rock. (See Pl. IV, *A*.) This confinement by air is not, however, close enough to give the best result with any explosive. By boring a hole in rock and tamping the explosive firmly in it, gunpowder and other low explosives may be made to break the rock, or a much less quantity of high explosive will break the rock than is required to break it when laid upon it. Confining an explosive is the cheapest and best way to use it.

Confinement essential to use of explosives.

It is foolish and dangerous for an inexperienced person to attempt to manufacture any kind of an explosive except under the supervision and direction of a trustworthy person who is skilled in the art. Many serious accidents, which have destroyed lives or inflicted injury on persons and property, have been caused by such attempts.

Folly of attempting to make explosives.

EXPLOSIVES.

As may be inferred from what has already been said, a large number of substances are known and used as explosives. The one longest known and used is gunpowder, which has certainly been used since early in the fourteenth century. This is made by intimately mixing 75 parts of India saltpeter (potassium nitrate) with 15 parts of charcoal and 10 parts of sulphur. Each of these ingredients is ground to a fine powder, and then they are ground together while moistened with water, in the proportions given, until the mixing is complete. The material is pressed into cakes, which are then broken up into grains, which are dried, glazed by rubbing, and sorted by the aid of sieves into the various desired sizes.

Gunpowder.

Formerly this India saltpeter powder was used both in guns and in blasting, and while to-day some of it is used in blasting, the larger part of what is used in this country under the name of black blasting powder is composed of 73 parts of Chile saltpeter (sodium nitrate or nitrate of soda), 16 parts of charcoal, and 11 parts of sulphur. This black blasting powder is made in a manner similar to that described for gunpowder, but less time is spent in making the mixture, and the charcoal is usually obtained from coarser-grained woods. The Chile saltpeter will

Black blasting powder.

supply more oxygen, and supply it more easily, than the India saltpeter, and therefore is a better and cheaper oxidizing agent; but the Chile saltpeter is not used in the manufacture of gunpowder because when it is exposed to moist air it takes up water by absorption from the air and becomes wet, and powder or other explosives in which this Chile saltpeter (nitrate of soda) is used likewise take up moisture when exposed to the air and become damp, so that it is difficult, and sometimes impossible, to set fire to them. As gunpowder for use in guns and firearms must often be kept for a great many years, and yet always be in such condition that it can be fired at any moment with certainty, this property of absorbing moisture from the air makes the nitrate of soda unfit for use in gunpowder; but blasting powder is not expected to be stored for years, and in magazines at mines it is quite possible to store it for a while so as to protect it from exposure to damp air. Besides, by proper management it is possible to obtain this blasting powder fresh from the manufacturer and use it promptly while in that condition; hence advantage may be taken, for economic use, of the superior efficiency and cheapness of the nitrate of soda in the manufacture of blasting powders if we keep them dry.

Danger from dampness.

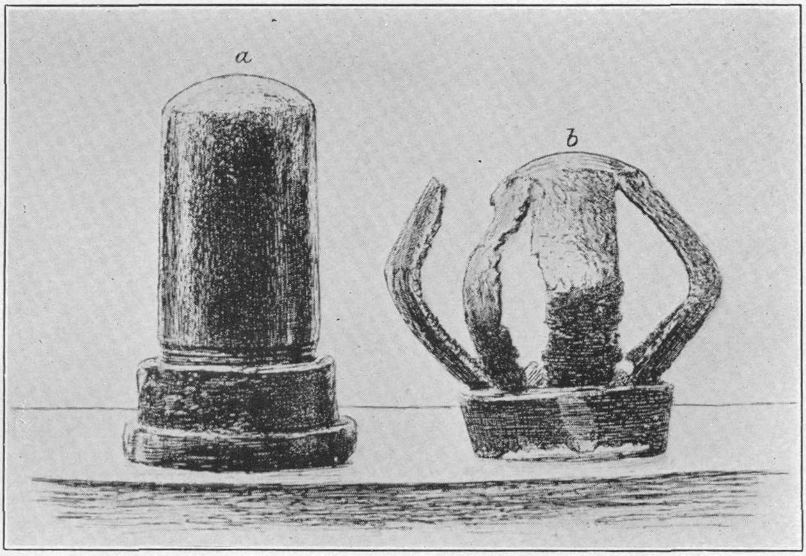
Keep powder dry.

Black blasting powder comes into the market in the form of grains whose edges have been rounded off by rubbing together in a revolving barrel and which are usually coated on the surface, or glazed, as it is termed, with graphite, or black lead. The object in rounding and glazing the grains is to render them free running, and the glazing also serves to delay somewhat the taking up of moisture from the air by the grains.

Granulating powder.

The powder is divided into grades according to the size of grains, as separated and collected by sieves of different sizes of openings. (See Pl. IV, *B*.) The sizes most usually offered for sale are called CC, C, F, FF, FFF, and FFFF. Of these, CC represents the largest grains, about one-half inch in diameter, and FFFF represents the smallest grains, about one-sixteenth inch in diameter. (See Pl. V, *A*.) The relation between the letters designating the sizes of the powder grains and the sieves by which the different sizes are separated is shown in the following table:

Size of powder grains.



A. EXPLOSION OF HIGH EXPLOSIVE IN BOMB FILLED WITH WATER.

B. SCREENS FOR SEPARATING DIFFERENT-SIZED POWDER GRAINS.

Relation between sizes of black blasting powder and separating sieves.

Size of grains.	Diameter of round holes in screens through which grains pass.	Diameter of round holes in screens on which grains collect.
CC	$\frac{1}{2}$ inch	$\frac{2}{5}$ inch
C	$\frac{2}{5}$ inch	$\frac{1}{3}$ inch
F	$\frac{1}{3}$ inch	$\frac{1}{5}$ inch
FF	$\frac{1}{5}$ inch	$\frac{1}{8}$ inch
FFF	$\frac{1}{8}$ inch	$\frac{1}{16}$ inch
FFFF	$\frac{1}{16}$ inch	$\frac{1}{28}$ inch [a]

[a] Square holes

Danger in using a mixture of different sized grains.

To get the best results in the use of this powder in blasting, the grains should be of uniform size, so that the miner, having determined the best size of charge, may have no difficulty in repeating it. Unfortunately, not enough care is taken in separating the grains into the different sizes, and powders have appeared in the market in which a considerable number of different sizes of grains were mixed together, so that the miner has obtained quite different results from his different shots in the same mine of coal with the same grade of powder. (See Pl. V, *B*.) Moreover, where large and small grains of powder are mixed in a charge, the fine grains, which burn freely, may produce, in burning, enough pressure to throw the large grains out into the mine where they can set the gas and dust afire. This makes such a mixture of grains a dangerous one in use.

Potassium chlorate.

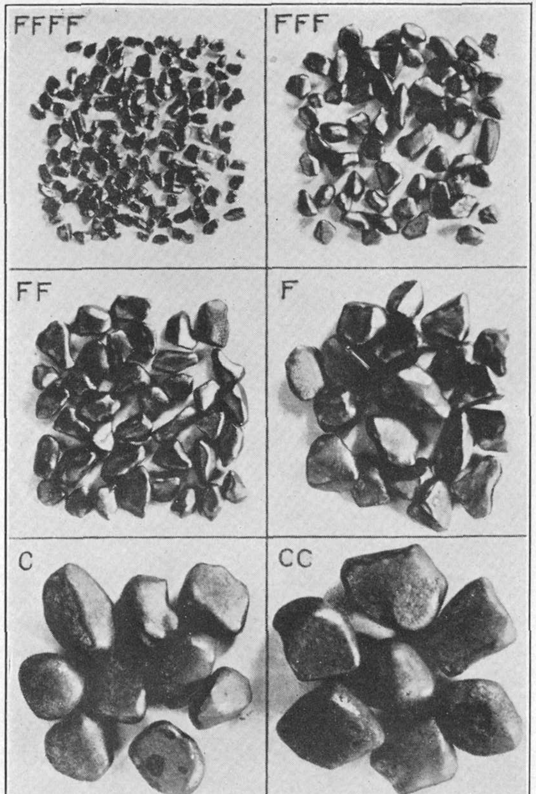
It has already been said that many other substances besides India saltpeter (potassium nitrate) and Chile saltpeter (sodium nitrate) are known which contain oxygen in such quantity and in such manner that they may be used as the oxidizing agents in forming explosives. Among these is the substance known as potassium chlorate. More than one hundred years ago an eminent French chemist showed that when it was mixed with combustible substances a most powerful explosive was produced; but, unfortunately, this mixture was found to be so sensitive to friction, blows, and heat as to endanger the lives of those who sought to handle and use it. Many of the mixtures produced with potassium chlorate are so easy to prepare and explode with such violence that a great many persons have been tempted to make them, but until recently all those that have been devised have been rejected as unfit for use because they were liable to destroy those who attempted to make or use them. It is found, however, that when dry and finely ground potassium chlorate is mixed with a body like starch, and with oil and other substances, an explosive is produced that is fairly safe to handle. Mixtures of this nature have met with some use in Europe.

Nitrocellulose.

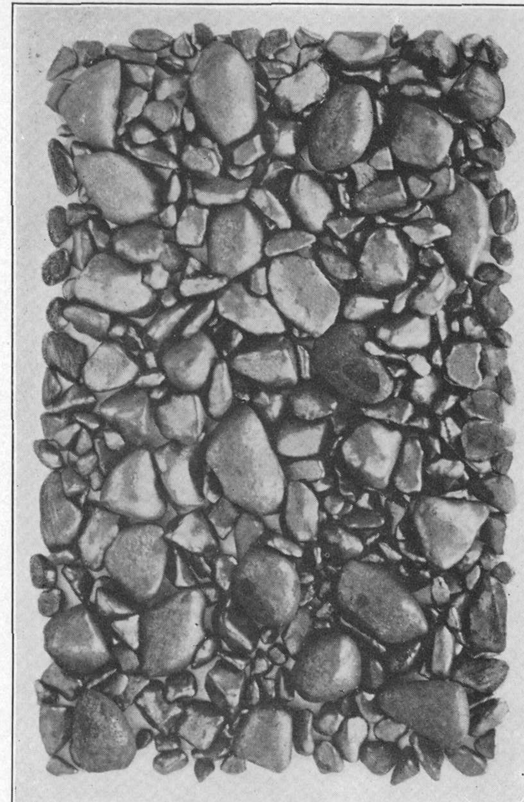
Attention has also been called (p. 14) to the fact that when purified dry cotton is immersed in nitric acid in the proper manner it is changed into an explosive substance through reaction with the nitric acid. When we withdraw the fibrous cotton from the nitric acid, wash it thoroughly to remove any acid that sticks to it, and then carefully dry it at a low temperature, the cotton appears unchanged to the eye, even when examined most carefully. It has, however, become a little harsh to the touch. When rubbed, it becomes electrified so that it sticks to the fingers, and when a flame is applied to it, it flashes off with great rapidity. In practice, a mixture of sulphuric acid is used with the nitric acid in nitrating the cotton. By varying the strength and the proportions of the nitric and sulphuric acids, their temperature when the cotton is dipped in them, and the length of time that the cotton is in them, we can get a number of different products varying in the rate at which they will burn and in the degree to which they are soluble in various solvents; but every such product results from the replacement of more or less of the element known as hydrogen, which was present in the cotton, by nitrogen and oxygen (indicated by the formula NO_2), which came from the nitric acid. Such a product, obtained by the action of the nitric acid on the cotton, will take fire and burn the more easily the greater the number of NO_2 groups that have replaced hydrogen in the cotton. We may, for convenience, divide these various products into two classes. Those which contain the fewer of these NO_2 groups are called pyroxylin, or soluble nitrocellulose, or collodion cotton, and those which contain the greater number of the NO_2 groups are known as gun cotton. In the manufacture of gun cotton the very strongest nitric and sulphuric acids are used. After the product has been washed so as to remove most of the acid sticking to it, it is pulped while wet into a fine powder in a machine such as is used in pulping paper stock, and when the gun cotton has been washed in this powdered condition so as to remove the last traces of acid, it is molded into blocks or sticks and is used as an explosive in that form.

Nitroglycerin.

Nitroglycerin is prepared by slowly running glycerin into a mixture of the strongest nitric and sulphuric acids, the whole being stirred and kept cool during the process of mixing. The reaction which takes place between the glycerin and the nitric acid is similar to that which takes place with the cotton. As a result of the reaction, NO_2 groups from the nitric acid replace hydrogen in the glycerin, and the mild, sweet, harmless glycerin is thereby changed into the powerful and dangerous explosive nitroglycerin. Nitroglycerin is a rather dense, oil-like liquid.



A. GRAINS OF BLACK BLASTING POWDER.



B. MIXTURE OF DIFFERENT-SIZED GRAINS OF BLACK BLASTING POWDER.

When pure it is colorless, but as it appears in the market it is usually pale yellow. It is somewhat poisonous, and one can be poisoned by it not only through the mouth but also by breathing its vapors or by allowing the liquid to touch the skin. A drop of it touching the tip of the finger will usually soon produce a violent headache. Fortunately, most persons lose their sensitiveness to poisoning after repeated contact, so that they cease to have the headache, but it would still be dangerous for these persons to get any of the nitroglycerin into the mouth. Nitroglycerin may freeze after some exposure to a temperature of 52° F. (see p. 26) and it must be thawed before it can be properly used as an explosive.

Nitroglycerin freezes.

Being a liquid, nitroglycerin is especially dangerous for ordinary use, because it may escape from the cans or other vessels in which it is carried or stored and run off to considerable distances, so as to increase the chances of accidental explosion by a blow, or friction, or heat; and also because it may, when placed in a bore hole, leak out into crevices or seams in the rock, and when fired give most undesirable results. In fact, during the middle of the last century, when it was offered for use, so many accidents occurred that many countries, by law, forbade its use or manufacture. We can, however, prevent a liquid from flowing about by absorbing it in a porous body, like a sponge. This has been done with nitroglycerin, and the product is called dynamite. Dynamite consists of nitroglycerin absorbed in a solid body called the dope. There are many dynamites. One of the earliest known and used was made by absorbing the nitroglycerin in powdered "rotten stone." As the "rotten stone" could neither burn nor explode, it was called an inactive dope, and there are several varieties of dynamites with inactive dopes. On the other hand, nitroglycerin may be absorbed in gunpowder. As the gunpowder explodes, as well as the nitroglycerin, when the dynamite is fired, the gunpowder is called an active dope. There are a large number of dynamites made with active dopes, and with varying percentages of nitroglycerin. The standard straight dynamite used at the Pittsburg testing station may be taken as an example of a dynamite with an active dope. It consists of the following:

Liquid nitroglycerin is especially dangerous.

Dynamite.

Composition of standard straight dynamite.

	Per cent.
Nitroglycerin	40
Nitrate of sodium	44
Wood pulp	15
Calcium carbonate	1
	100

Explosive gelatin and gelatin dynamite.

Since it is a liquid, nitroglycerin, like other liquids, acts as a solvent, and it has been found that under certain conditions it can dissolve soluble nitrocellulose, and that the mixture thus formed will set to a jelly-like mass. In this way, or sometimes by the use of other solvents also, the substance known as explosive gelatin is formed, a substance that in some respects is regarded as the most nearly "ideal" explosive. However, it is too powerful for ordinary use in blasting, and it is therefore diluted by mixing it with a dope, such as the nitrate of soda and wood pulp used in straight dynamite. The mixture so formed is known as gelatin dynamite.

All explosives containing nitroglycerin freeze.

It has already been said that nitroglycerin when exposed to ordinary winter temperatures will freeze. Dynamite, explosive gelatin, and gelatin dynamite will also freeze, because all of them contain nitroglycerin, and, like nitroglycerin, all of these substances should be properly thawed before any attempt is made to use them.

Dynamite cartridges.

Each of these substances is put upon the market in the form of sticks or cartridges, which are made by wrapping up cylinders of the material in paper. The wrappers for dynamite and gelatin dynamite are paraffined to protect them from the action of water and the moisture in the air, because they contain nitrate of soda and hence may absorb moisture and become spoiled, and develop new sources of danger in handling and use. These sticks usually vary in size from seven-eighths inch to 2½ inches in diameter, and they are usually 8 inches long. They are usually packed in cases containing 50 pounds each. The mark "This side up," or a design on the top of the case, shows the position in which the cartridges are packed. The cases should always be placed so that the cartridges lie on their sides, and they do lie so when the cases are stored with their top sides up.

Packing dynamite.

For use in coal mines it is suggested that the explosive be packed in cases or cartons containing the weight which the law of the district permits being taken into the mine. (See Pl. VI, *B*.)

Nitrostarch.

Besides cotton and glycerin, there are a large number of substances, such as sugar and starch, that are chemically related to cotton and glycerin and through the action of nitric acid, particularly in the presence of sulphuric acid, give rise to explosive substances. Many of these have been produced, but so-called nitrostarch is the only one that seems to have any commercial importance. During the last ten years this has attracted some attention, and it has been offered for use both in this country and in Europe. It is a finely powdered substance like starch itself, but it does not need, as starch does, to be suspended in the air in order to explode on ignition, because even when in a pile it will burn with great rapidity if set afire, and through the action of a detonator it explodes with great violence. It is not yet used by itself, but is used as a component in various explosive mixtures, particularly dynamites.

Ammonium nitrate.

Attention has been called to the use of potassium nitrate and sodium nitrate in the manufacture of explosives. In recent years another nitrate, formed by the union of ammonia with nitric acid and known as ammonium nitrate, has come to be somewhat largely used. It has been used in this country for more than a quarter of a century in the manufacture of some dynamites, taking the place of sodium nitrate and having the advantage over it that on explosion it goes completely into gases; but it has come to be used in Europe in the manufacture of special explosives for use in coal mines, for the reason that on explosion it forms a large amount of water, and this lowers the temperature of all the products of the explosion. In the making of several of these ammonium-nitrate powders, various substances obtained from coal tar, which generally have been acted upon by nitric acid, are mixed with the ammonium nitrate.

Nitro-substitution compounds.

The substances derived from the coal tar, after having been acted upon by the nitric acid, are known as nitro-substitution compounds. One of the substances obtained from coal tar which is perhaps best and longest known is carbolic acid, and when this reacts with strong nitric acid it gives us the nitro-substitution compound known as picric acid. Other substances obtained from coal tar that are pretty well known are benzene, toluene, and naphthalene. When these are acted upon by nitric acid we obtain from them the nitro-substitution compounds known as nitrobenzene, nitrotoluene, and nitronaphthalene. These are but a few of the many substances that may be obtained from coal tar and furnish, through the action of nitric acid upon them, nitro-substitution compounds. All the nitro-substitution compounds will form explosives when mixed with oxidizing agents such as ammonium nitrate, or other nitrates, or chlorates, and many explosives have been made from such mixtures. Moreover, these nitro-substitution compounds have been used as components of dynamites, particularly because they lower the freezing point of the nitroglycerin in the dynamites.

Why nitro-substitution compounds are so called.

The nitro-substitution compounds are so called because the NO_2 groups in them, obtained from the nitric acid, are directly connected to the carbon atoms in the original material, replacing hydrogen atoms; whereas in gun cotton, nitroglycerin, and bodies of that sort, the NO_2 groups are linked to the carbon atoms of the original substance by means of atoms of oxygen. The nitro-substitution compounds are usually yellowish to red crystalline solids, but as most of these solids are easily melted, they are often sent out in compact masses. A few of them are liquids at ordinary temperatures, and they have a marked aromatic odor. Some of these substances are poisonous. Great care should be taken in handling all of them, and one should especially avoid breathing their vapors.

Fulminates.

As has been stated above, the most common fulminates are produced by dissolving a metal, such as mercury, in a strong nitric acid, and pouring the solution into common alcohol. When the proportions used are correct and the operation is carried out in a proper manner, after an apparently violent reaction there will be produced a mass of fine, gray crystals that look quite alike, and this is known as fulminate of mercury, or mercury fulminate. The crystalline powder thus produced is washed with water to free it from acids, and because of its extreme sensitiveness it is kept soaked with water until desired for use. It is principally used in loading blasting caps or detonators, and for this purpose the water may be removed from it by alcohol and it may be loaded into the copper capsules while wet with alcohol, but it should be always borne in mind that this mercury fulminate, even when thoroughly soaked with or sunk under water or alcohol, will explode with tremendous violence if only a small amount of the dry fulminate be exploded while touching it, or very near it. Hence extreme precautions should always be taken with mercury fulminate, whether the substance be wet or dry.

Danger with fulminates.

The manufacture of explosives is by no means simple. Unless all the materials are of the proper kind and in the proper condition, and they are used in the proper order, in the proper manner, with the proper tools and vessels, and with all the proper precautions at each stage of the operation, the manufacture is a very dangerous thing to undertake, and it is very foolish for anyone to undertake it by himself.

Warning against manufacturing explosives.

EXPLOSIVES FOR USE IN COAL MINES.

Number of explosives.

It is evident that a large number of different explosives can be formed by mixing various combustible substances with various oxidizing agents, or by using such mixtures as dopes for dynamite, or by using them together with the different nitro-substitution compounds. In fact, the number is so great that a book published in 1895 gave the names of more than one thousand different explosives, and many have been added to the list since that date. As the number of those in actual use is much smaller, it is clear that most of the explosives known are, for various reasons, unsuitable for use; indeed, no one of those more generally known is suitable for use under all circumstances. For instance, some of them on explosion give off a considerable volume of flame; some of them on explosion give off considerable volumes of poisonous or noxious gases; some of them explode so quickly as to shatter the rock or other material in which they are fired and break it down into fine pieces; some of them are too bulky; and so on.

Explosives in open work.

It is evident that if we are seeking to break down the rock in an open quarry for the purpose of making use of that rock as ballast for roads, we can employ an explosive that produces a long flame, or gives off poisonous gases, or shatters the material, because the work is done in the open air, and because the rock has to be broken up into small pieces anyway, so that it is well for the explosive to do it. If, however, we sought to get out from that quarry blocks of stone such as marble or granite, which were to be used in building or for monuments, we should avoid using the shattering explosive and choose one that slowly, and without a shock, separates the rock mass from the deposit. Yet for this purpose also, as the work is in the open air, it might matter little if the explosive gave rise to a large flame or gave off poisonous gases, provided the quantity of explosive used was small.

Explosives in inclosed work.

But the conditions in a coal mine are very different from those in a quarry. The mine is inclosed and not out in the open air, and, moreover, it is liable at any time to contain inflammable gases or coal dust, or both, which may form explosive mixtures with the air.

Danger from flames in coal mines.

If under these circumstances an explosive were used which gave off a long flame on firing, this flame, darting out from the bore hole, might set fire to the explosive mixture in the mine and produce a mine explosion. (See Pl. VI, *A*.)

Noxious gases.

Moreover, as the mine is an inclosed space and as the wholesomeness of the air within it depends upon artificial ventilation, it is also objectionable in such a mine to make use of an explosive giving off any considerable quantity of noxious gases, which must be removed from the mine after the explosion before the miner can safely return to his work.

Investigation by Geological Survey.

Considerations such as these have led to an investigation by the United States Geological Survey of the explosives offered in the market, for the purpose of determining, in the interest of the coal miner, which of such explosives are suitable for use in coal mines and will do the work with the greatest degree of safety for the miner using them. Of course, it is impossible to insure complete safety, for no explosive can be perfectly safe and every explosive should be treated with the greatest care and consideration.

Testing station at Pittsburg.

Explosives gallery No. 1.

With this object in view the United States Geological Survey has established a testing station at Pittsburg, Pa. (see Pl. I, frontispiece), where there has been erected a large gallery made of steel, 100 feet long by 6 feet 4 inches in diameter, and so made that it can be filled with fire damp, or with coal dust and air mixed, or with gas, dust, and air mixed in any desired proportion, so as to reproduce the dangerous conditions that may occur in coal mines. Attached to one end of the gallery is a very strong "gun" with a chamber representing the bore hole in a mine. From this "gun" various exactly determined quantities of the explosive to be tested may be fired, either untamped or tamped, into the mixture in the gallery, and thereby it can be learned whether or not the definitely known quantity of explosive used as described will cause the ignition and explosion of the mixture in the gallery. Besides this gas and dust gallery there is at the testing station a collection of other apparatus and appliances by which to test the various properties of explosives, and so to find their relative value and their relative safety for use in coal mines. This investigation has been going on since September, 1908, and there have already been published two lists of explosives that have passed all test requirements in a satisfactory manner and are considered to be suitable for use in coal mines, provided they are used under the prescribed conditions.[a]

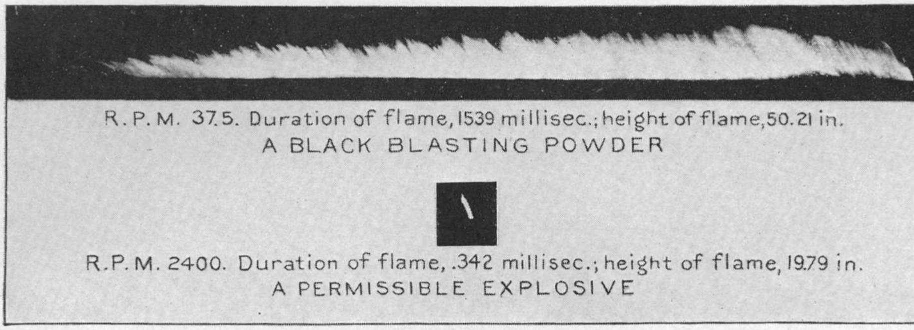
Permissible explosives.

These approved explosives are, therefore, called by the United States Geological Survey "permissible explosives." The name of each brand that has passed the tests up to October 1, 1909, together with the name of the manufacturer, is given in the following list:

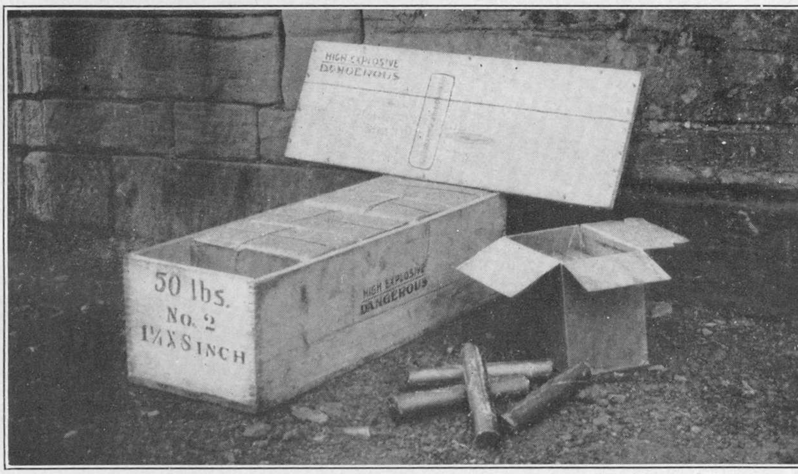
List of permissible explosives October 1, 1909.

Brand.	Manufacturer.
Ætna coal powder A	Ætna Powder Co., Chicago, Ill.
Ætna coal powder AA	Do.
Ætna coal powder B	Do.
Ætna coal powder C	Do.
Bituminite No. 1	Jefferson Powder Co., Birmingham, Ala.
Black Diamond No. 3	Illinois Powder Manufacturing Co., St. Louis, Mo.
Black Diamond No. 4	Do.
Carbonite No. 1	E. I. Du Pont de Nemours Powder Co., Wilmington, Del.
Carbonite No. 2	Do.
Carbonite No. 3	Do.
Carbonite No. 1-L. F	Do.
Carbonite No. 2-L. F	Do.
Coalite No. 1	Potts Powder Co., New York City.
Coalite No. 2-D	Do.
Coal special No. 1	Keystone Powder Manufacturing Co., Emporium, Pa.
Coal special No. 2	Do.
Collier dynamite No. 2	Sinnamahoning Powder Manufacturing Co., Emporium, Pa.
Collier dynamite No. 4	Do.
Collier dynamite No. 5	Do.

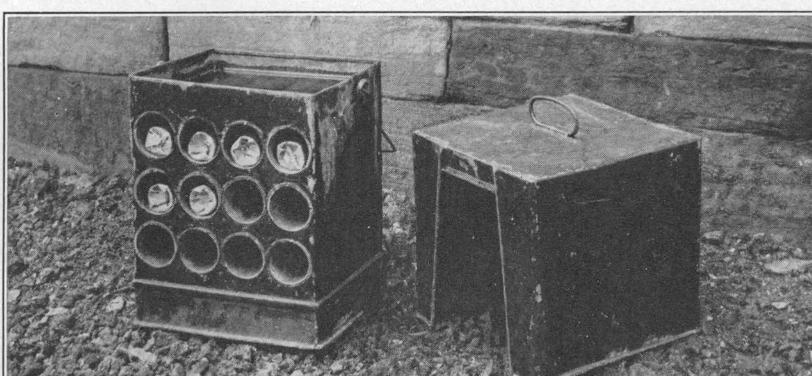
[a] See p. 60 for prescribed conditions under which each of these explosives is to be used.



A. FLAMES FROM EXPLOSION OF EQUAL WEIGHTS OF BLACK BLASTING POWDER AND OF A PERMISSIBLE EXPLOSIVE.



B. BOXES OF DYNAMITE, SHOWING METHOD OF PACKING IT.



C. THAWER FOR FROZEN EXPLOSIVES.

List of permissible explosives October 1, 1909—Continued.

Brand.	Manufacturer.
Giant A low-flame dynamite	Giant Powder Co. (Consolidated), Giant, Cal.
Giant B low-flame dynamite	Do.
Giant C low-flame dynamite	Do.
Masurite M. L. F.	Masurite Explosives Co., Sharon, Pa.
Meteor dynamite	E. I. Du Pont de Nemours Powder Co., Wilmington, Del.
Mine-ite A	Burton Powder Co., Pittsburg, Pa.
Mine-ite B	Do.
Monobel	E. I. Du Pont de Nemours Powder Co., Wilmington, Del.
Tunnelite No. 5	G. R. McAbee Powder and Oil Co., Pittsburg, Pa.
Tunnelite No. 6	Do.
Tunnelite No. 7	Do.
Tunnelite No. 8	Do.

Classification of permissible explosives.

With reference to the characteristic component of each of these permissible explosives, they may be placed in three classes—ammonium nitrate powders, represented by Ætna coal powder AA, Collier dynamite No. 5, Masurite M. L. F., and Monobel; hydrated powders, represented by Meteor dynamite and Giant A, B, and C; and nitroglycerin powders, represented by all the others on the list. With the exception of Masurite M. L. F., all the powders mentioned in the list contain nitroglycerin, and therefore they are all of the general nature of dynamite; but the components and proportions of the dope have been so chosen and the mixtures so made as to modify very greatly the shattering effect upon explosion, while at the same time the volumes of gases produced are relatively cool. As a result, the flames produced are short and not lasting, and coal is thrown out without being powdered, when the proper charge of such an explosive is used and this charge is properly placed. These explosives are designed to take the place of black blasting powder, which has been found to be unsuited for use in coal mines where dangerous gas or inflammable dust is present, because of the great mass of flame which it produces and the long time that this flame lasts, and because of the quantity of poisonous smoke and noxious gases which it gives out when exploded. Although explosives of the kind represented in the list of permissible explosives have been introduced into this country only during the last few years, yet their consumption now amounts to several million pounds annually and is rapidly growing.

Advantages of permissible explosives.

Danger from permissible explosives.

Unfortunately, though the permissible explosives are good coal getters and yield short flames that do not last and gases of low temperature, so that there is little danger of igniting the explosive gases and dusts in mines when they are used, still the gases they yield on explosion may be noxious and inflammable; and miners are warned, when using permissible explosives, not to return to the breast after firing them any sooner than they would if they had fired a charge of black blasting powder.

From what has been said regarding nitroglycerin, it follows that all these permissible explosives, except Masurite M. L. F., will freeze when exposed long enough to low temperatures, and they must be thawed before they can be properly used. It is true that in making several of them, especially those marked L. F., materials have been added that prevent their freezing so readily, but the manufacturers do not claim that such explosives will remain unfrozen when the temperature falls below 35° F. To keep any of the nitroglycerin explosives permanently thawed, they should be stored where the temperature does not go below 52° F. On the other hand, care should be taken that none of these explosives is subjected to high temperatures, for this will render all of them more sensitive to explosion and is likely to cause the decomposition of some of them. It is best that the temperature of magazines in which they are stored should not rise above 90° F.

Freezing of permissible explosives.

Danger from exposure to high temperatures.

Explosives should not be exposed for any length of time to direct sunlight, because this may lead to decomposition in those containing nitroglycerin, nitrocellulose, nitrostarch, or substances of that kind. Explosives should be stored in a dry place, for many of them contain considerable quantities of ammonium nitrate or of sodium nitrate and so will take up moisture from damp air and become damp. Too great dampness makes the explosive not only harder to fire, but weaker when fired. Besides, if the explosive is damp the nature of the gases produced will be different. Moreover, as bodies like dynamite become moist, the nitroglycerin contained in them tends to run out; that is, what is called exudation takes place, and all the dangers follow that belong to liquid nitroglycerin.

Do not expose to sunlight.

Keep explosives dry.

On the other hand, explosives should not be kept in an extremely dry place, for all of them, as made, contain some moisture, and if the place of storage is very dry the explosive may lose this moisture. Such a change in composition will affect the explosive so as to change the speed with which the explosive reaction takes place within it, and therefore the character of the work which it does when exploded. Naturally, the longer an explosive is kept in storage the greater are the chances that change will take place in it, and therefore the explosive should be obtained in as fresh a condition as possible and should be used as soon as possible after it is received. Also, it should be kept stored

Do not dry explosives too much.

Use explosives promptly.

in its original packages in the magazine outside the mine until wanted for immediate use, and then used promptly.

Injury to cartridges from rough handling.

Dynamite is put up in sticks, which are wrapped in paper, and the cartridges so formed are usually dipped in paraffin to make the wrapping waterproof. As by rough handling the folded edges may be broken open and the contents of the cartridge thereby exposed to the moisture of the air, these cartridges should be handled with great care, and they are best carried to the place where they are to be used in the cartons in which they are bought.

Care in handling cartridges.

In handling explosives the greatest care must be taken to prevent their falling or getting shocks. They must not be thrown or dropped, and portions of the powder falling from the cartridges must be carefully guarded against friction, blows, or fire.

Shipment of explosives.

Explosives should never be carried by railroad except in conformity with the rules of the Interstate Commerce Commission, as published by the American Railway Association. These rules make it unlawful to carry any explosives, except small-arms ammunition, on any public vessel or vehicle carrying passengers.

Storage of explosives.

Explosives should be stored in properly placed, built, and aired magazines. Such a magazine should be far enough from other buildings or works so that if an accidental explosion occurred when the magazine was full it would do the least possible damage, and it should be so placed as not to be in danger from forest, brush, or other accidental fires.

Magazines.

Magazines are best built of brick or concrete, but they are more frequently built of wood covered with corrugated iron. In any case they should be provided with wooden floors, which should be kept free from grit and dirt. It is best that only one kind of explosive should be kept in any one magazine. If more than one kind of explosive (other than permissible explosives) must be kept in the same magazine, the magazine should be divided into rooms, by partitions, and the different explosives kept in different rooms.

Detonators never to be stored with other explosives.

On no account should detonators, or blasting caps, or any device containing fulminating composition, be kept in the same magazine with any other explosive. These firing devices should be kept in a dry place by themselves.

Plans and specifications for magazines will be furnished by manufacturers of permissible explosives. (See also pp. 57–59, and figs. 11 and 12.)

The greatest care must be taken to prevent packages of explosives from falling or getting shocks. They must not be thrown, dropped, nor rolled. Wooden boxes containing explosives should be opened with extreme care, so as to avoid friction and blows as much as possible. They should never be opened within the magazine, but in a properly sheltered place outside of the magazine and at a distance from it. They should be opened only by the use of a wooden mallet and a hardwood wedge.

Opening boxes of explosives.

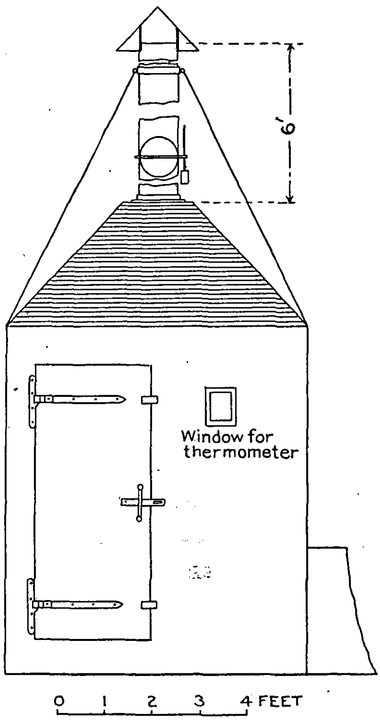


FIGURE 1.—Thaw house for frozen explosives; elevation.

Thawing frozen explosives.

The thawing of frozen explosives requires extreme care, and doing it improperly has frequently led to most serious accidents. No attempt should ever be made to thaw a frozen explosive by placing the cartridge before a fire, or near a boiler, or on steam pipes, or putting it in hot water, or by placing it in the sun. While thawing, nitroglycerin explosives are extremely sensitive and should be handled with great care. During the thawing the nitroglycerin tends to separate from the dope and run out from the cartridge (that is, to exude), and this is a source of danger.

When but a small amount of the explosive is required, it may be thawed in the thawers that are furnished by all the manufacturers of explosives and have been found safe for use as directed. (See Pl. VI, *C*.) The thawer consists of a water-jacketed tin vessel, in which the cartridges are placed and which is closed with a tin cover. Before the water is placed in the vessel it is warmed up to a temperature not uncomfortable to the hand put into it, and the cartridges are allowed to remain in the thawer until it is found, by gently pressing them, that they are completely thawed throughout. When thawed, the material will feel plastic, or like flour, between the fingers. When frozen, or partly frozen, the stick will feel more or less rigid and hard. It is necessary that the stick should be thawed completely, because dynamite when frozen can be detonated only with great difficulty, and any part that is frozen will be

Thawers for explosives.

Complete thawing necessary.

but imperfectly detonated in the hole; hence not only may such partly frozen powder fail to give its full effect as an explosive, but there is danger of a serious accident in a coal mine where such powder is used, because if a blown-out shot results the burning solid part may set fire to the dust or fire damp in the air of the mine.

Thaw houses.

Where large quantities of explosives are used daily, a small thaw house should be provided for the purpose of thawing out the frozen explosive. (See figs. 1 and 2.) Plans and specifications, together with a bill of material for such a thaw

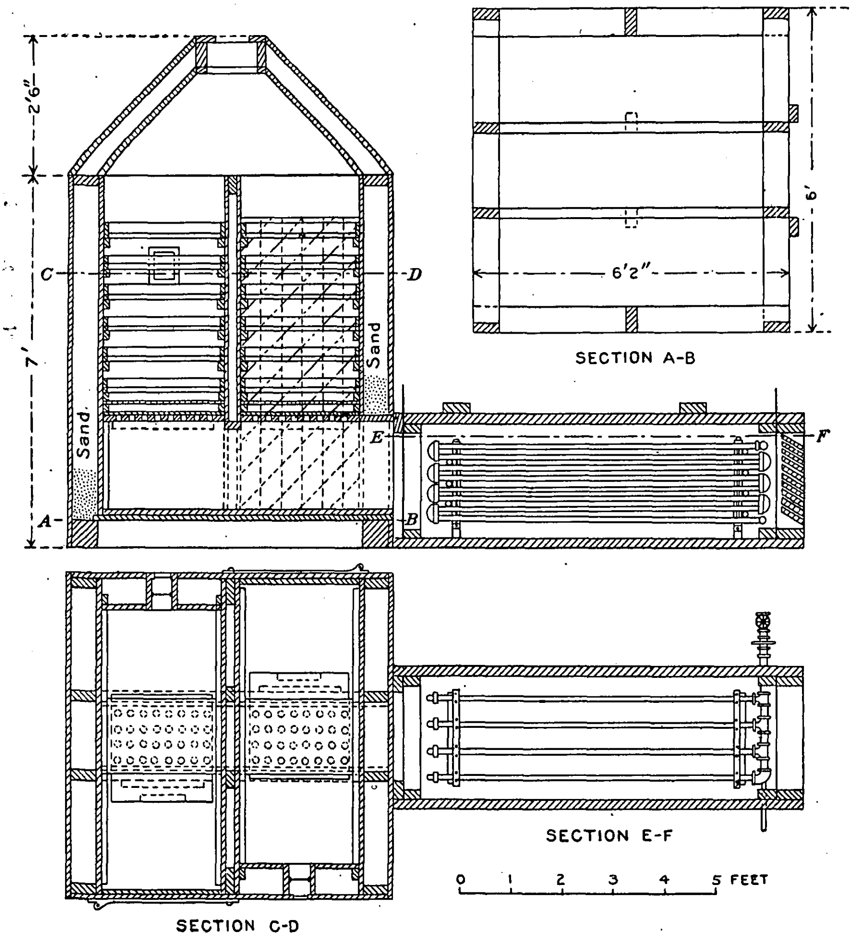


FIGURE 2.--Thaw house for frozen explosives; section.

house, will be furnished, on application, by the manufacturers of permissible explosives. The thaw house should be large enough to hold all the explosives used in one day's work. It should be heated by a small hot-water heater, placed at least 4 yards from the house, the hot water being passed into the house through iron pipes, at such a rate that the temperature in the house will not at any time be above 90° F.

Thaw houses are intended only for the treatment of explosives for immediate use, and not for the storage of explosives, for if powders or dynamites are left in this high temperature and dry air for a considerable time, the moisture that is a proper part of them will be driven off, and, as stated before, this will markedly alter the character of the powder or dynamite and may lead to accidents in its use.

Thaw houses not to be used for storage.

SQUIBS, FUSE, AND DETONATORS.

It has been made clear in the discussion of combustion and explosion and the description of various explosives that they can be caused to explode by various means. All of them can, under some circumstances, be made to explode by fire. Some of them can be caused to undergo a detonating explosion by setting off a detonator in contact with them. In blasting use is made of both these means for setting off explosives, the means used being determined by circumstances.

Means of exploding explosives.

In setting off by means of fire, use is made of miner's squibs, or of fuse. Miner's squibs (Pl. VII, *A*) consist of tapering paper tubes about 7 inches long, filled with fine gunpowder, one end of each paper tube being treated with chemicals so as to form a slow-burning match, which, when ignited, burns so slowly as to give the miner time to reach a place of safety before the explosion. When used the squib is placed in the needle hole, or blasting barrel, through the tamping, with the match end of the squib outward. When the match is ignited the fire burns slowly along the tube until it reaches the powder core. Then the squib darts forward like a rocket, leaving a trail of flame behind which spurts out from the needle hole, and the fire continues burning along the powder core of the squib until it bursts out of the other end of the tube and so ignites the charge.

Miner's squibs.

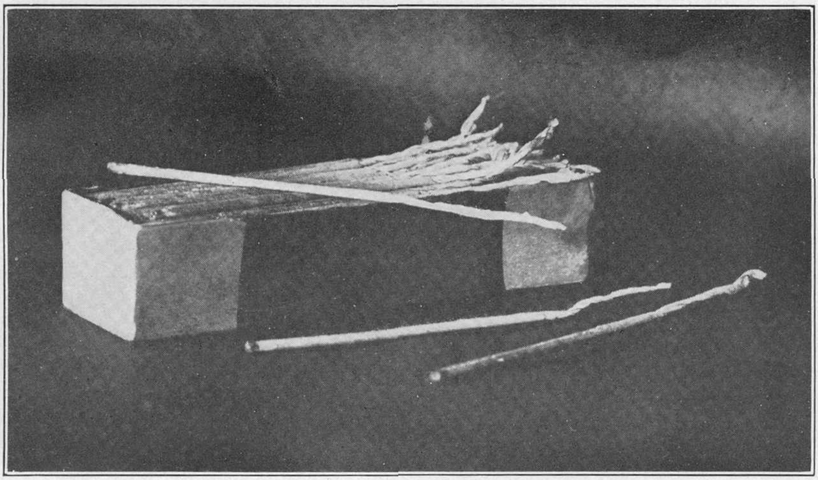
How squibs work.

In experiments made at the Pittsburg testing station it has been found that, though the burning match on the end of the tube of the squib does not inflame a mixture of mine gas and air, as soon as the powder core is ignited the flame that then flashes out from the end of the squib will explode the mixture. Hence squibs should not be used in any gaseous mine.

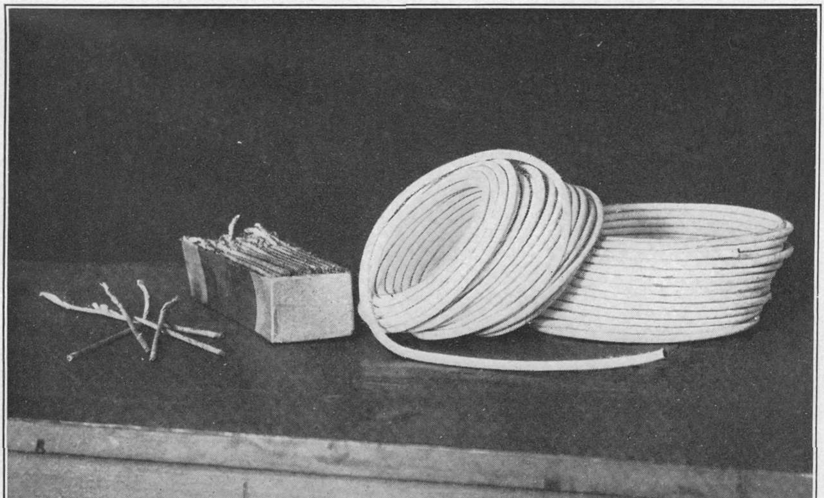
Squibs should not be used in fiery mines.

Fuse, as used in coal mines, is sent out into the market in coils 50 feet long, and in several varieties, but all consist of a core of mealed gunpowder inclosed in two or more layers of yarn and generally surrounded by tape that has been dipped in a waterproofing composition. (See Pl. VII, *B*.) Some varieties are then dusted with substances like powdered soapstone, to prevent the sticky surfaces from sticking to one another.

Fuse.



A. MINER'S SQUIB.



B. MINER'S SQUIB AND FUSE.

The kinds of fuse most commonly used are hemp fuse, cotton fuse, single-tape fuse, double-tape fuse, triple-tape fuse.

Action of fuse. When one end of a fuse of any variety is lighted the powder core burns slowly along the fuse till at last the flame rushes out at the farther end and, if it touches a charge of powder, sets it off. Like squibs, fuse throws off flame when lighted, and hence the use of fuse in a gaseous mine can not be recommended. **Testing fuse.** Fuse should be so made and should be in such a condition when used that any part of any coil will burn at the rate of 1 foot in eighteen to twenty seconds. This is of the greatest importance, because in setting a charge the blaster or shot firer cuts a piece of fuse to reach from the charge to the opening and long enough to give him ample time, after the end has been set on fire, to reach a place of safety before the flame fires the charge. Therefore, careful tests should be made of the rate of burning of pieces of the fuse whenever there is any doubt whatever as to its soundness. **Fuse injured by bad handling.** Although the manufacturers may produce a fuse with a regular rate of burning, the rate may be changed by bad handling, as, for instance, by squeezing the fuse so as to disturb the powder core, or by suddenly and roughly opening the coil when it is stiff from cold, so as to crack the fuse; or the fuse may be injured by rubbing against the rough surfaces of the rock. **Care in cutting fuse.** In cutting the fuse and in fitting it into place, care must be taken that the powder core does not run out from the fuse, for that might cause a misfire.

Detonators. Detonators (which are also called blasting caps, and sometimes are called exploders, though the last term applies to any means of producing an explosion, and therefore is not commended here) consist of copper capsules about as thick as an ordinary lead pencil, which are commonly charged with dry mercury fulminate or with a mixture of dry mercury fulminate and potassium chlorate that is compressed in the bottom of the capsule, filling it to about one-third of its length.

Advantage in use of detonators. Dynamite and other detonating explosives are in practice fired by means of detonators, for though they may be exploded by the aid of squibs or fuse, or by means of gunpowder primers, yet the explosion so produced is not a complete one; the explosives are not used to their best advantage; all of the work that they can do is not done; and, moreover, the gases that are produced are usually dangerous. Where high explosives are employed, it is safer to fire with detonators strong enough to cause their most complete explosion. Permissible explosives should be fired by detonators, and are best fired by electric detonators of the strength prescribed for each one. (See p. 61.)

Grades of detonators.

Several grades of these blasting caps or detonators are to be found in the market, and they are differently designated by different manufacturers. The "strengths" of the detonators most commonly used, as measured by the weights of the fulminating composition contained in them, are as follows:

Grades of detonators and weight of their charges.

Testing-station grades.	Commercial grades.	Weight of charge in grams.	Weight of charge in grains.
No. 3	3X, or triple	0.54	8.3
No. 4	4X, or quadruple	0.65	10.0
No. 5	5X, or quintuple	0.80	12.3
No. 6	6X, or sextuple	1.00	15.4
No. 7	7X, or No. 20	1.50	23.1
No. 8	8X, or No. 30	2.00	30.9

Attaching detonators to fuse.

Detonators are fired by the aid of a piece of fuse. The end of the fuse is inserted in the mouth of the blasting cap and carefully pushed down until it gently touches the surface of the detonating composition, and then the cap is crimped onto the fuse. (See Pl. VIII, *A*.) The cap, with the attached fuse, is inserted in the charge to be fired, which, when placed in the bore hole and tamped, is ready for firing. The end of the fuse is lighted, and the fire burns down the powder core until it streams against the detonating composition, which then detonates and causes the detonation of the explosive with which it is in contact.

Fuse not to be used in fiery mines.

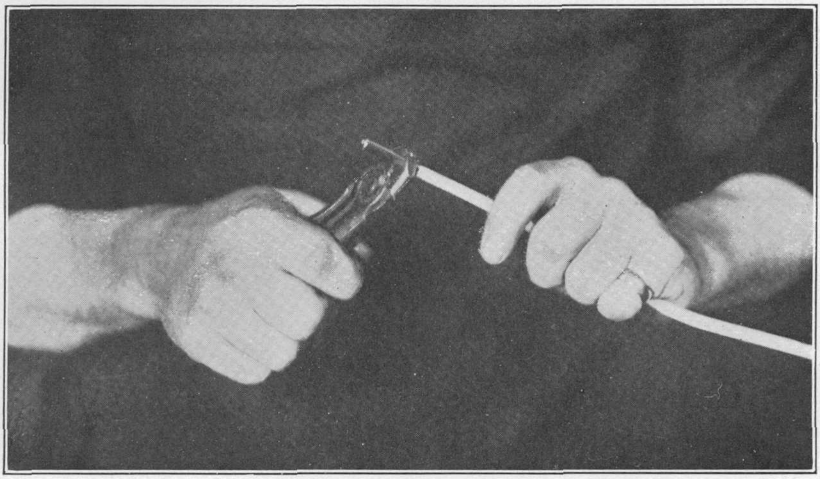
It has been found at the Pittsburg testing station that the flame which rushes out from a fuse when it is ignited at the mouth of a bore hole will ignite an explosive mixture of mine gas and air. Therefore fuse should not be used, either alone or with detonators, in fiery mines.

Fuse and detonators must be of standard size.

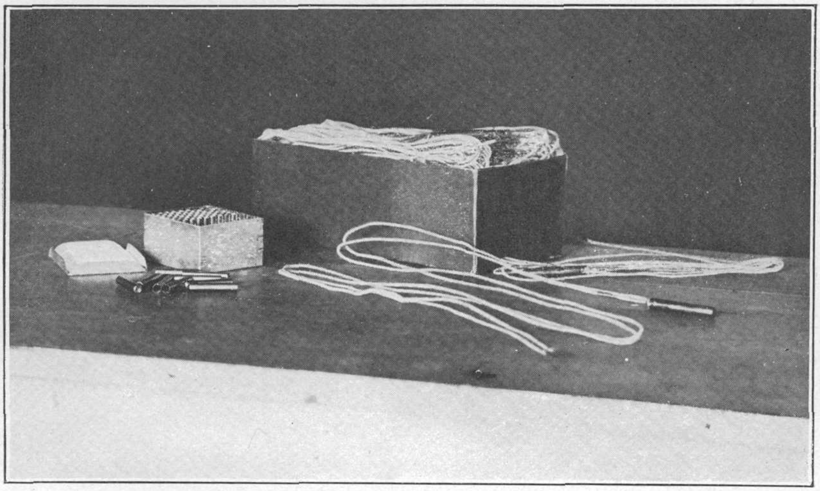
The practice of fitting the fuse to the detonator is common in quarries, tunnels, and mines that are not gaseous. Accordingly, it is customary to make both detonators and fuses in standard sizes, so that the fuse may easily slip down within the mouth of the detonator and yet make a neat fit within it.

Electric detonators.

By the use of electric detonators (also called electric fuses), the dangers that are common in the use of squibs or fuse in gaseous coal mines are avoided. (See Pl. VIII, *B*, and fig. 3.) These electric detonators are simply ordinary detonators that have been fitted with a means of firing them by the electric current. This is done by inserting within them two copper wires, joined at the inner ends by an extremely fine platinum or other high-resistance wire, which, like the carbon filament in the ordinary incandescent lamp, becomes heated till it glows when an



A. CRIMPING DETONATOR ON FUSE.



B. DETONATORS AND ELECTRIC DETONATORS.

electric current is passed through it. This wire, known as the bridge, is placed above the detonating composition, and is surrounded by gun cotton or loose fulminate. The space above it and the mouth of the capsule are then filled and closed by means of a plug of sulphur or other waterproof composition, which is poured in while soft. The copper wires pass through the plug and are long enough to extend outside the capsule. These outer ends are called the legs or wires of the electric detonator. Although the copper wires are bare within the electric detonator, the legs outside are covered with an insulating wrapping. These legs are made of different lengths in order to suit different depths of bore holes. The charge of detonating composition differs in the different grades of electric detonators so as to give different strengths.

Grades of electric detonators.

The following table gives the grade and weight of charge for the more common electric detonators:

Grades and weights of charge of electric detonators.

Testing-station grades.	Commercial grades.	Weight of charge in grams.	Weight of charge in grains.
No. 5	Single strength	0.80	12.3
No. 6	Double strength	1.00	15.4
No. 7	Triple strength	1.50	23.1
No. 8	Quadruple strength	2.00	30.9

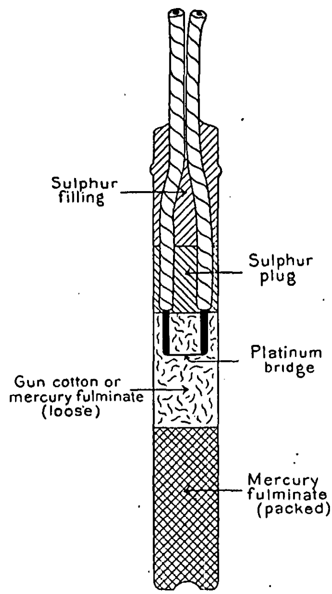


FIGURE 3.—Electric detonator, showing its component parts.

Firing electric detonators.

In loading bore holes electric detonators are placed in the charge just as detonators with fuse are, and the bore holes are tamped in a similar manner. To fire the charge, the legs of the detonator are connected by leading wires to an electric device at a safe distance, and from it the current is sent to fire the blast. No flame can escape from the bore hole during the firing, for the tamping fills the hole completely, and hence blasting in gaseous mines is made much safer.

Only electric detonators are used at the Pittsburg testing station in the tests of explosives for use in mines.

Delay-action electric detonators.

What are called delay-action electric "exploders" or detonators are now being offered for use where a number of holes are to be fired at once, but so that the charges may explode one after another. This is done by placing a piece of fuse or other device in the electric detonator between the detonating composition and the bridge and inclosing the whole so that the flame may not escape from the blast hole. In the present state of knowledge this practice is not commended for use in coal mines.

Danger in use of detonators.

In the description of mercury fulminate attention was called to its extreme sensitiveness to heat, friction, or blows and to the extreme violence of the explosion which it undergoes. All these properties therefore belong to detonators and electric detonators, and these little devices should be treated with the utmost respect. Never attempt to pick out any of the composition. Do not drop them or strike them violently against any hard body. Do not lay them on the ground where they may be stepped on. Do not step on them. In crimping, take the greatest care not to squeeze the composition, and never crimp with the teeth, for there is enough composition in one of these small capsules to blow a man's head open. They should be stored in a dry place and in a building apart from any other explosives. They should never be carried into a mine with other explosives, and they should never be placed in a mine near other explosives except in bore holes. When carried or shipped they should be packed firmly with a quantity of elastic material, such as felt or the coiled legs of the electric detonators, about them, and they should not be exposed to heat, blows, or shocks of any kind.

MINING COAL WITH EXPLOSIVES.

Conditions in coal mines.

No universal rule can be made for blasting coal, for the local conditions, the character of the seam, and the method of working make it necessary to use different means in different mines and sometimes even in different parts of the same mine. The best method of blasting in any given mine or part of a mine is determined by practical experience and observation.

The placing of bore holes, as well as the size of the charge, is of vital importance. In placing them special attention and due consideration should be given to the bedding and cleavage planes in the seam; also to slate and bone parting, horsebacks, clay slips, and other local irregularities.

Shooting off the solid.

In this country, apart from the not widely used long-wall system and the pillar pulling or withdrawing, in both of which little or no explosive is used, there are two general methods of bringing down coal in entry driving or room work, namely, "shooting off the solid" and undercutting or shearing before shooting.

In the coal mines of the middle interior fields, where shooting off the solid is largely practiced and where there are no marked faces or butts, the following method is used: A hole is bored or drilled in the face at or near the middle of the seam, at such a slant as to make a small angle with the face. If an imaginary line (AB in fig. 4) drawn from the back of the drill hole at right angles to the hole passes out of the open face, and if that distance is not too great, the hole is rated as "safe" by those who use the method. If, however, the hole extends beyond A to X (fig. 4), the extended part is said to be "dead" and the hole is considered "unsafe." A hole is also considered "unsafe" if the angle ACB is greater than 35°. In the softer coals and where the joints or cleavage planes (cleat) are favorable a greater angle is used, but no drill hole, even under such favorable conditions, is bored at an angle greater than 45°.

Need of slow-acting explosives.

In shooting off the solid only one face of the coal to be thrown off is exposed. It must be torn off along the line AB and AC (fig. 4) and in addition must be forced out along the bedding planes at top and bottom. Where such bedding planes are smooth this is not difficult, but generally they are irregular, and a strong shearing force must be exerted parallel to the bedding planes, both at the top and bottom. This method to be effective requires a slow-acting explosive, and black blasting powder has been much used in the work.

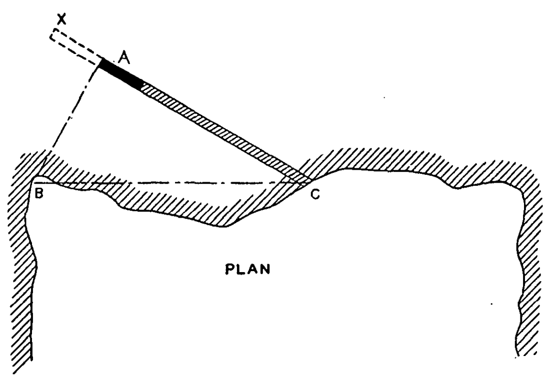


FIGURE 4.—Shooting off the solid.

Dependent shots.

A second hole and even a third one is sometimes drilled and charged before the first one is fired, and these are called "dependent" shots. The fuses are sometimes made of different lengths and lighted at the same time, with the expectation that the shots will go off in the proper order. Such practice is now generally held to be very wrong even in "solid shooting" districts. The second and third holes should not be drilled until after the first shot has been made, so that the location of each shot can be properly judged.

Overcharging.

The size or weight of the charge in shooting off the solid varies much in different coals. In fact, it is extremely difficult, even in the same coal, to judge the amount correctly each time. If undercharged, the hole is likely to "blow out;" hence it follows that holes are almost invariably overcharged, and in some districts all sense of right proportion has been lost by the miners.

Aside from the dangers in the use of black powder, the uncertainties in proportioning the charge to the work are such that the method of shooting off the solid can not be approved as either precise or safe. Many of the great mine disasters of this country have undoubtedly started from misjudged or overcharged shots off the solid.

Undercutting and shearing.

The other method of bringing down the coal, in which the explosive is assisted by undercutting or shearing beforehand and which was early used in this country, is now being readopted in most parts of the country. The object of undercutting or shearing is to expose two faces of the mass of the coal to be brought down, and, as coal generally tends to break along vertical planes, to permit the explosive to exert a wedging effect, rather than to shear or tear off the mass as it must in shooting off the solid.

There are two ways of applying this method—shearing and undercutting. Occasionally, where the coal is hard to shoot down, both shearing and undercutting are done, so that a less amount of explosive is needed; in fact, in some places none is required, as the coal can be wedged down.

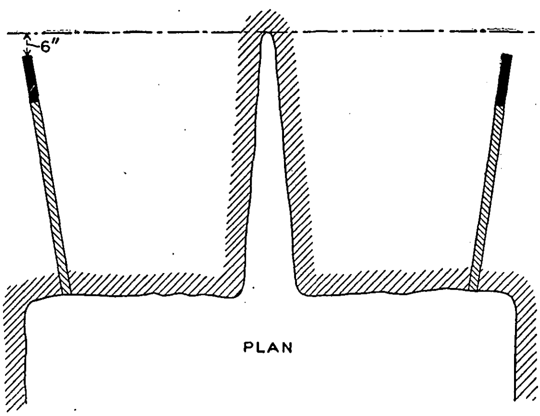


FIGURE 5.—Shearing.

Where the cutting is by hand and the top and bottom part "freely," shearing is the easier, and is usually employed in entry or narrow work. In some cases the shear or vertical cut is made on but one rib, but generally it is made in the center of the narrow face and the shot is so placed as to throw the coal toward the shear.

Shearing.

Where the coal is all alike in character and parts equally well at top and bottom the hole is started at or near the middle of the seam and drilled nearly parallel with the shearing, slanting a little upward to cross the bedding planes, and also to clear itself of dust as it is being drilled. The hole should never go deeper than the cutting, and it is better for it not to go as deep by at least 6 inches as the cutting. In figure 5 the back of the bore hole is shown as reaching the projected line of the rib, but in softer coals the backs of the bore holes are usually at least 6 inches from the projected line of the rib.

In districts where black powder is still used it is conceded that a shot hole of this character should never be charged with more than

2 pounds of black powder, and better with much less. It is difficult to make rules for an exact amount, because the proper amount differs with the length of the hole and cutting, the strength of the coal, and the way that it parts from top and bottom. However, the work should never be so laid out that it will require more than 2 pounds of black powder. If one of the permissible explosives is used, the charge should be, in general, only about one-half (by weight) what would be required if black powder were used; but no work should be so laid out—that is, no drill hole should be so located with reference to the shearing—as to require more than a pound and a half of the explosive.

Charge of explosive in shearing.

Where the place is so wide that another hole is required near the first, when the first has done its work properly a similar situation is left for the second hole.

Where the coal is undercut, either by hand or machine, the purpose of the shot is to bring down the mass of coal by wedging from above. In such a place the greater part of the force of the explosive used in the first shot will go to shear off the coal on both sides of the shot, the expanding gases from the explosive working along the bedding plane at the line of the drill hole and the mass pivoting at the back of the undercutting. The stronger the bedding of the coal—that is, the less marked the vertical lines—the more difficult is this shearing, which then becomes a tearing, rending effect at the sides of the mass, so that the shape of the mass is somewhat conical, the top being at the line of the drill hole and the base at the undercutting. Under the circumstances the coal above the drill hole generally does not come down, but it is usually so shattered that it may be pulled down with a pick. Necessarily this first shot takes more explosive than later shots, but the amount should never be more than that already stated for the shearing method.

Undercutting.

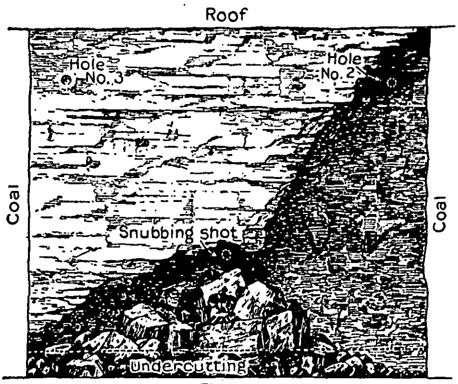


FIGURE 6.—Snubbing shot.

Charge in undercutting.

To help the first or "buster" shot, if the undercutting has been done by machine, it is advisable, and in some cases necessary, that the coal at the front edge of the undercutting be "snubbed" off either by the pick or by a small "pop" or "snubbing" shot (fig. 6). In narrow work, if the

Placing of the shots.

"buster" shot has done its work properly at one rib, the second shot is placed at the other rib. In wider work the "buster" shot is usually placed near the center of the room face and the second and third shots are placed on either side (fig. 7). Each of these is so placed as to throw down a mass of coal which practically has three faces free—the front, the bottom, and one end. The chief work of the shot is to wedge off the rib end and push away from the back. Such a shot usually only requires from one-half to three-quarters of a pound of one of the permissible explosives. The work should be adjusted to these charges, so that if three shots besides the snubbing shot (if one is needed) are not enough, four or even five shots should be used. It is far safer to use a number of shots with a small amount of explosives in each than to use a few shots with a larger amount; and on the whole less explosive will be needed in all the small shots than in the few large shots.

Advantage of small charges.

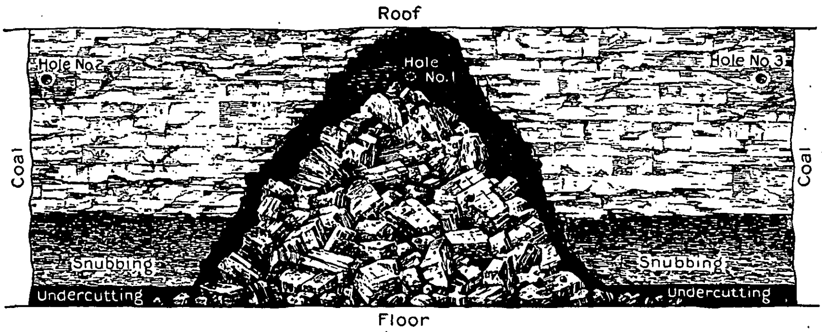


FIGURE 7.—First or "buster" shot.

Depth of undercutting.

The depth of the undercutting varies with the character of the coal and with the thickness of the seam, but in hand-pick work the depth is not commonly greater than the thickness of the seam. Where machines are used to undercut, the depth is from 6 to 7 feet, depending on the machine. With machines the cutting is usually done at the bottom of the seam; if the seam is thin (less than 3 feet) the cutting is done in the underlying clay, if there is any. Where the undercutting is done by hand pick, it is sometimes done in a soft layer near the middle of the seam, or in a parting of soft clay, but so far as the placing of the shots is concerned, the part above such an undercutting may be regarded as a thin seam, the coal below the cutting being lifted afterward by "heaving" shots. Generally the cutting is in the bottom, and where it is so the shots are usually placed above the middle of the coal and sometimes near the top. Where the coal is undercut and black blasting powder is used, owing to the powder's slow wedging action the exact position of the shot is not of such special importance as it is where permissible explosives are used. As already explained, these are quicker in action than black blasting powder, and unless they dislodge the coal instantly their force is spent in shattering the coal near the drill hole. Therefore with permissible explosives the mouth and back of the drill hole should be nearer the roof and the hole should slant upward in order that the back of the drill hole may reach the top bedding plane (fig. 8). The break will then be clean and a wedging action will be exerted along the top bedding plane.

Care in using permissible explosives.

In the use of permissible explosives, special care should be taken that each bore hole has the same width throughout and is wide enough to permit the cartridges to pass through it without too hard ramming. Too small a hole may cause the cartridge to stick, and nitroglycerin explosives or even black powder may be exploded by the friction of the tamping bar against the sides of the hole. Daily attention should be given to the drills that are used in drilling the bore holes, and the points of the bits when being sharpened should be made to a standard size.

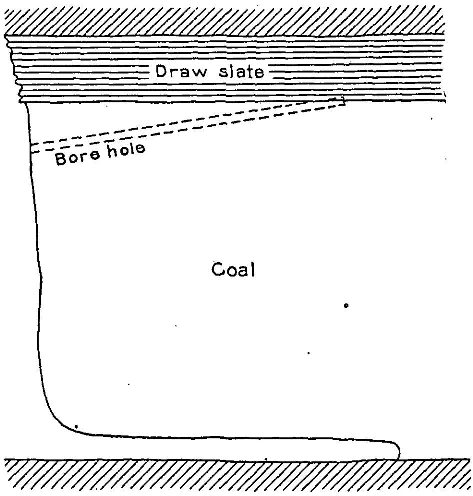


FIGURE 8.—Bore hole for permissible explosives.

Dust must be wet down and removed.

Before a shot is fired in a working place "bug" dust and all other coal dust should be thoroughly wet and sent out of the working place. No cause of explosions has been more common than the presence of coal dust when shots are being fired. If the working place is naturally dry, it should be thoroughly sprinkled, and all the ribs, roof, and props within 40 feet of the shot washed down by hose before shots are fired.

Humidifying mines.

Good results have been obtained in bituminous coal mines during the winter months by warming and moistening the air entering the mine by means of exhaust steam and spraying devices. In experiments made in December, 1908, at the Pittsburg testing station the outside air entering the gallery was warmed up to a mine temperature and moistened by drawing it through humidifiers. It was found that if the air is kept at a relative humidity of 90 per cent and a temperature of 60° F. for forty-eight hours, thus giving conditions like those of summer in a mine, the taking up of moisture by the dust and the blanketing effect of the moist air prevent a general ignition of the dust by a blown-out shot of black powder.

Since the new permissible explosives began to be used it has been found that more satisfactory results are obtained in mines where the loading and tamping of all shots are done by a few competent men known as "shot firers."

Shot firers.

For the greatest safety the loading and firing of all shots should be done by shot firers after all other men have left the mine. The practice of having all shots loaded and fired by shot firers during the shift, which has lately been introduced in some of the mines of the Pittsburg district, is certainly a step in the right direction.

It is plain that the greatest safety and best work can not be obtained when the miners are allowed to load and fire their shots, because the new permissible explosives must be properly handled to get the desired results. The shot firers should be selected from the more intelligent miners, and they should be thoroughly instructed in the great dangers that arise when the permissible explosives are used in any other manner than that specified by the Pittsburg testing station.

LOADING AND FIRING CHARGES OF EXPLOSIVES.

Loading bore holes.

In blasting, any explosive gives the greatest disruptive effect when the charge most completely fills the bore hole from side to side. If the explosives are supplied in cartridge form this condition can often be obtained in the bore hole by splitting the wrapper, gently pushing a cartridge down into place in the bore hole with a tamping stick, gently

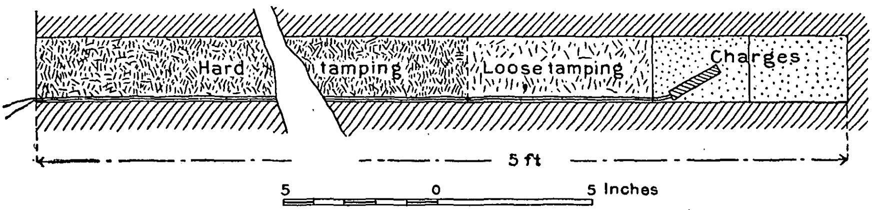


FIGURE 9.—Bore hole ready for firing.

squeezing it so that it spreads out to fill the entire width of the hole, and repeating this with each cartridge until the charge has all been put in. Finally, the detonator is placed in the last cartridge put in, and this cartridge is known as the primer. The primer is gently pushed down into place in firm contact with the remainder of the charge, and the hole is tamped (fig. 9).

Primer.

If the same weights of different explosives are of equal strength, the one that takes up least space—that is, the densest—will have the greatest effect in breaking coal or rock. Of two cartridges of equal size containing different explosives the heavier cartridge is said to have the greater density.

Density of charge.

Loading black blasting powder.

Black blasting powder to be used in blasting is made up into a cartridge by means of a paper wrapper which has been formed about the handle of a pick. When this cartridge has been charged with powder, the electric igniter or fuse is placed and well fastened, and the cartridge should then be gently pushed down into the bore hole by means of a wooden tamping stick, which is safer than any metal bar. An iron tamping bar should never be used. When squibs are used, the cartridge of powder is placed in the bore hole and then the tamping is put in about a copper or brass needle rod until the hole is filled. Then the copper needle is withdrawn and the squib is put through the opening.

Tamping stick.

Placing fuse and tamping.

When only fuse is used, it should be long enough to reach beyond the mouth of the bore hole. The tamping should be packed in about the fuse quite to the mouth of the bore hole, and the fuse should be completely surrounded by tamping.

Danger of firing untamped holes.

It is observed that in some mines the practice has been to use but a short length of fuse and to let the charge explode untamped, or simply secured by running the tamping bar into the hole. This is a very bad and dangerous practice and should be forbidden.

Fitting fuse in detonator.

When detonators are used together with a fuse, the fuse should be cut off squarely at the end, gently inserted within the detonator until the powder core touches the detonating composition, and then, with the fuse held in the left hand, the detonator should be crimped onto the fuse with crimpers close to the open end of the cap, so as to make a perfectly tight and secure joint, care being taken in crimping that no pressure is brought to bear upon the detonating composition.

Fitting fused detonator in primer.

Two ways are in use of inserting the detonator and attached fuse into the stick of explosive that goes on top of the charge and is known as the primer. The more approved way is to open the top of the cartridge or stick of explosive by unfolding the paper at the end; then to make a hole by means of a wooden skewer or lead pencil in the top of the cartridge, deep enough to let the detonator be pushed into it up to the line of crimping; then to gather the end of the paper jacket or envelope together about the fuse, the whole being bound with twine, so as to fasten the detonator and fuse firmly in place.

Another way that is sometimes used is to insert the wooden skewer into the side near the upper end of the priming cartridge so as to make a slanting hole in the charge, deep enough to take the detonator up to the crimping mark, then to insert the detonator and bind it and the fuse close to the cartridge with twine. (See Pl. IX, *A*.)

The first way is perhaps more generally used, and it is better where the cartridge fits neatly into the bore hole. When the second way is used, the bore hole must be larger, as there should be some leeway between the cartridge and the side of the hole. In either way, when the primer, with the detonator and fuse, is put into the bore hole, extreme care should be taken that they do not come apart, for if there is any space between the cartridges in a charge, or particularly between the detonator and the explosive in the priming cartridge, the explosion may be prevented altogether, or may be a very poor one. Likewise, when a fuse and detonator are used in loading, care should be taken that the detonator is not completely buried in the explosive, for as the fuse burns and fire rushes from its end some of it may blow out over the top of the detonator and set fire to the explosive about it before the detonator is set off. This has been a common cause of inferior and dangerous explosions.

Be careful not to pull detonator out of primer.

Detonator must not be completely buried.

The same sort of trouble happens if coal dust or any other dirt is allowed to get between the cartridges in a charge, or between the priming cartridge and the charge. In loading, extreme care should be taken to make sure that the cartridges all touch one another closely.

Dirt between cartridges.

When electric detonators are used they are fastened in the priming cartridge in ways like those described above for detonators used with fuse. When the electric detonator is inserted in a hole in the side of the priming cartridge, the practice has sometimes been to fasten it firmly by taking a half hitch around the priming cartridge with the legs of the detonator, the loading and tamping being then done as already described. This last means of attaching the electric detonator to the priming cartridge is not a good one, because the legs are likely to become kinked, and also because there is a chance that when the priming cartridge is pushed into place the insulation may be rubbed off from the legs and the wires may be short-circuited.

Fastening electric detonators.

Although it has been stated that with certain explosives, which are somewhat largely used, the cartridge case may be split and the charge rammed firmly into place, this is not the universal practice and should not be done with all the ammonium-nitrate class of explosives (p. 21), nor with some of the nitro-substitution explosives, for if they are tightly rammed in the bore hole, it is difficult or even almost impossible to explode them.

Some explosives, if split and tightly packed, may not explode.

After the priming charge with its fuse and detonator or its electric detonator has been inserted in the bore hole, the hole should be tamped with clay or with other material that can not burn. It should never be tamped with coal dust (either wet or dry) or with machine cuttings, known as "bug dust." The tamping should be done by means of a wooden tamping stick. The pressure in tamping should be very gentle on the first tamping material put in, particularly if detonators are used in the primers, and great care should be taken at this time not to disturb the position of the detonator in the primer. Special care should be taken not to draw the detonator out from the primer or the fuse out from the detonator. When fuse is used, care should also be taken not to rub the surface off of it.

Instructions for tamping.

After the first 6 inches of the tamping material has been pressed down, greater force may be used in ramming the rest, because the firmer the tamping is the better is the work of the explosive and the less is the chance of a blown-out shot. The tamping should be continued quite up to the mouth of the bore hole. If fuse has been used, the upper side of it near the end may now be cut into on a slant, with a sharp knife, and the outer part bent away so as to form a

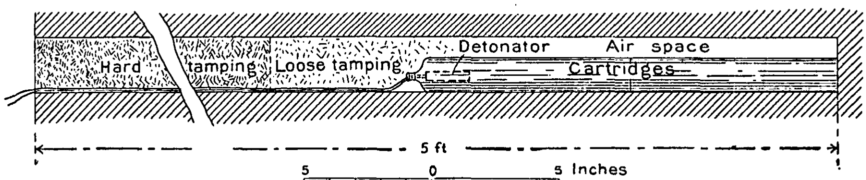


FIGURE 10.—Loaded bore hole showing air space about the charge.

notch in which the powder from the core gathers and to which the igniter is applied. This cutting prevents the loss of powder from the fuse and makes it easier to light.

The shattering effect of high explosives may be lessened in loading simply by pushing the cartridges into place without splitting or afterward squeezing them, so that an air space will be left about the cartridges in the bore hole, and then proceeding with the priming and tamping. This air space notably lessens the shattering effect of the explosive (fig. 10).

Air spacing of charge to reduce shattering effect.

Where it is desired to use black blasting powder, electric black-powder igniters, sometimes called electric safety fuses or squibs, are recommended for setting off shots. They are made in a general way like electric detonators, but gunpowder or other slow-burning composition is used in them instead of detonating composition. They are much safer for use in coal mines than ordinary squibs or fuse, both because they do not throw fire into the mine air and because they permit better tamping of the bore holes.

Electric igniter.

It sometimes happens that it is desired to fire a number of charges at the same instant. This is readily done with electric detonators by coupling them up in series from hole to hole and firing by one discharge from the machine. This method endangers the roof and may cause falls. In mines other than coal mines it may be done by instantaneous fuse running from a central fuse to the several charges, but this practice is not a good one in coal mines, because the fuse may set fire to the dust or gas that is present.

Instantaneous fuse.

In coal mines it is more commonly desired to fire one or more of the charges before the other charges, and this may be done in a single act of firing by the use of the delay-action electric detonators already described (p. 33). An ordinary electric detonator is placed in the charge for the central breaking-down shot, and delay-action electric detonators are placed in the charges for the right and left rib shots. This method of firing has many advantages over the methods of firing successive shots by means of different lengths of running fuse, but neither method is recommended for use in gassy or dusty coal mines.

Delay-action detonators.

The safest way is to fire but one shot at a time, and to allow time enough between shots for the ventilating current to mix with and render harmless the products of combustion from the previous shot and to carry off any coal dust that may have been thrown into the air by the shock of the previous shot. The interval of time that should elapse between shots differs with local conditions and the amount of ventilation, but in ordinary mining practice the interval should never be less than five minutes for shots made in the same working place.

Safety in single shots—Time between them.

In the making up of charges for loading bore holes and during the loading, extreme care should be taken that the explosives are not exposed to the flames from naked lamps or to sparks from the striking of metals upon each other or upon rocks, or from any source, since any of these may cause serious accidents.

Danger from flame and sparks.

As already suggested, the right size for a charge of explosive for blasting in a coal mine can be found better by practice than by theory. Several formulas have been devised by which to determine the right charge beforehand, but unfortunately they have not given satisfactory results in practice. If the material or mass to be blasted were always alike throughout, and of equal hardness, theoretical rules could be made to apply, but such is not the fact. Differences in the resistance of the material to be blasted and in the rate of burning or detonation and the breaking force of the different explosives all affect the results of a blast.

Failure of formulas for size of charges.

Comparison of effects of different explosives.

Thus, for instance, in soft bituminous coal a permissible explosive containing only 20 per cent of nitroglycerin has been found to bring down more coal, and better coal, than one made under a similar formula but containing 25 per cent of nitroglycerin. A very quick explosive should not be used in bituminous coal mines where lump coal is sought. For instance, 40 per cent dynamite, which has been found by experiment at the Pittsburg testing station to have a rate of detonation of 4,688 meters (15,380 feet) per second is unsuitable for producing lump coal; but the permissible explosives that have rates of detonation between 1,866 and 3,617 meters (6,122 and 11,867 feet) per second are found to be well adapted for this work. Explosives that develop very high pressures are also unsuited for this work. Thus the 40 per cent dynamite referred to above has been found to produce a pressure of 8,308 kilograms per square centimeter (118,165 pounds per square inch), but the permissible explosives show pressures as low as 4,833 kilograms per square centimeter (68,740 pounds per square inch).

Size of charge of permissible explosives for coal mines.

In deciding on the charge of a permissible explosive for use in a coal mine it is safe practice to use about one-half the weight of black blasting powder that would be needed to do the work; but no charge of permissible explosives should be more than 1½ pounds. As stated before (p. 39), bore holes for permissible explosives are placed by a different rule for depth and direction than that which is followed when black powder is used. No permissible explosives nor any high explosive should ever be used in the same bore hole with black blasting powder.

Objections to overloading.

The most obvious objections to overloading are that it crushes and wastes the coal, and that it throws fire and flame out into the air of the mine. Another objection is that the surplus force of the shot may so weaken the roof and surroundings as to cause falls, which may not occur, however, for some time after the shot has been fired.

Objections to underloading.

Underloading, on the other hand, not only causes loss and waste, but it may so fissure the coal near by as to make it dangerous to fire another shot near the place. At the same time it may happen that the underloaded charge, though not strong enough to bring down the coal, may spring the bore hole, throw out the tamping, and give a blown-out shot; that is, a charge that is not heavy enough to make a blast may be heavy enough to act in a bore hole as it would in the barrel of a gun; and this may happen particularly if the tamping is not well secured and firm. Blown-out shots are especially to be feared in dusty and gassy mines, because it has been found that explosive mixtures, such as are present in such mines, are most sure to catch fire and burn most completely when a mass of flame, and more particularly a mass of glowing solid particles, is thrown into their midst. Investigation has shown that the larger number of the recent disasters in coal mines have been due to blown-out shots.

Premature explosions, misfires, and hang fires.

Premature explosions, misfires, and hang fires are most likely to happen when squibs and fuses are used to set off charges, owing to defects that may be in them from the first, or may be caused in the handling, carrying, or loading of them. Miners are especially warned in case of a hang fire to avoid returning to the breast until half an hour has passed. Hang fires rarely happen with electric detonators, but it is possible that they may happen more often with delay-action detonators.

Keep away from a hang fire for half an hour.

Partial explosions.

Incomplete explosions may result from several causes. They may be due to failure to push in all the cartridges of a charge till they touch one another, thus leaving an air space between them, or else a mass of coal dust or dirt, which breaks the path of the detonation from cartridge to cartridge. They may be due to the pulling out, even but a little way, of the detonator from the primer or of the fuse from the detonator. In the use of nitrate of ammonia or nitro-substitution powders, incomplete explosions may be due to too tight packing and compressing in the bore hole. In any case, a partial explosion is a marked source of danger; first, because it may have the effects of an underloaded charge; second, because the unexploded part of the charge may burn and throw out flame and sparks into the mine, and also give out poisonous gases and fumes; third, because the unexploded part of the charge, if it is not burned up, may be brought down with the coal and give rise to an accident in the breaker, or, if it passes the breaker, to an accident in the transportation or the use of the coal. Whenever there is a partial explosion, if coal has been brought down, careful search should be made in the coal for the remainder of the charge.

In case of a misfire no attempt should be made to draw the charge, but a new bore hole should be placed at least 2 feet away from the first one and fired, and after the coal has been brought down it should be carefully looked over to find any unexploded material that may have come from the hole that misfired. When a hole charged with black blasting powder has misfired the tamping and charge may be withdrawn, drenching them with water while withdrawing them. After the hole has been dried out it may be reloaded.

FIRING BLASTS BY ELECTRICITY.

Danger of firing by flame.

The methods used in causing the explosion of charges in blasting depend on the nature of the explosive. To cause the explosion of an explosive of the black-powder class, it is only necessary to put a flame to it, but a violent shock is necessary to cause the detonation of high explosives so that they will have their greatest breaking effect. As already stated, black-powder charges are set off by means of squibs, fuse, or electric igniters. Squibs and fuse are set on fire by means of the flame of the miner's lamp, or sometimes by heating a wire to the glowing point in the miner's lamp and applying it to the match of the squib or the cut end of the running fuse; but evidently these methods would be dangerous in fiery coal mines, and hence they should never be used in such mines.

Connecting legs to leading wires.

An electric igniter or an electric detonator should be so loaded into a bore hole that while it is in perfect contact with the charge the legs of it reach at least 6 inches out of the completely tamped hole. Both legs should be bared of their insulation for about 2 inches from their ends, and the wires scraped bright so that a good electrical contact can be made with them. Each leg is then firmly connected with one of the leading wires by about five turns. It is bad practice to have the two splices directly opposite each other, because when the leading wires are pulled the splices may touch one another and thus make a short circuit, which will prevent the electric igniter or electric detonator from being exploded. A better plan is to wrap the bare wire splices with tape made for the purpose, which will completely insulate them.

Splices should not be opposite—Wrapping splices.

Connecting leading wires to firing machine.

After the legs are spliced to the leading wires (and only after), the wires are connected to the firing machine from which the electric current is to be obtained. This last connection should never be made until all the men are at a safe distance from the place where the blast is to be fired. The rule should be made and never broken that when bore holes are charged the connecting up shall move from the bore hole back to the firing machine. The work in the mine should be so organized that it can never be possible for the leading wires to be coupled up to the firing machine while anyone is about the place where the holes are being charged and where the blast is to be fired. In heavy blasts in development work, two or more electric detonators may be used to good advantage in the same bore hole. For this purpose they are connected up in series, which means, for two detonators, that a leg of each is bared and the two legs twisted together and wrapped with insulating tape, and

All connections to be made from bore hole to firing machine.

Connecting detonators in series.

that then the two free legs are attached to the leading wires, just as where but a single detonator is used. In coal mining the charge used should never be so large as to require the use of more than one detonator in the same hole.

Connecting holes.

When it is desired to fire two or more holes at the same time the detonators for these holes should also be connected up in series, and to bridge the space between the holes a cheap insulated wire, known as connecting wire, which is not as heavy as the leading wires, may be used. In coupling up a series of holes for this purpose, one leg of a detonator is connected to one leg of the detonator in the next hole, and so on to the last hole. There is then left one free leg in the first hole and one free leg in the last hole, and these are spliced to the leading wires. The usual precautions should be taken to wrap all the splices with insulating tape, so as to completely insulate them, and thereby insure a good circuit through which the current may pass. It should be borne in mind that the greater the number of holes to be fired in a single blast the greater is the necessity for making sure that the circuit is complete throughout, because if there is a break or a short circuit at any point, the blast will probably fail to fire. The delay, expense, and danger caused by such a failure can be prevented by giving careful attention in the first place to the charging and the wiring.

Danger from a break or short circuit.

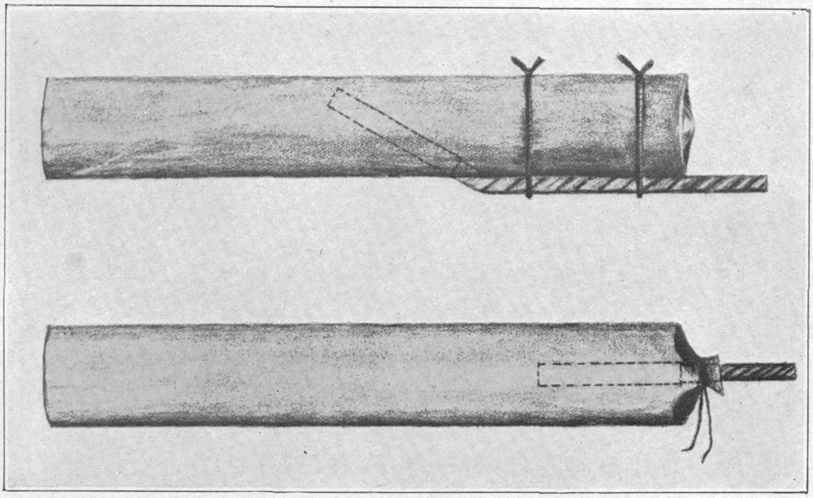
Sources of current.

The electric current for use in firing electric igniters or electric detonators may be obtained either from primary batteries, such as dry-cell batteries, or from secondary batteries, such as storage batteries, or from electric-lighting circuits, or from generators known as electric firing machines. (See Pl. IX, *B*.)

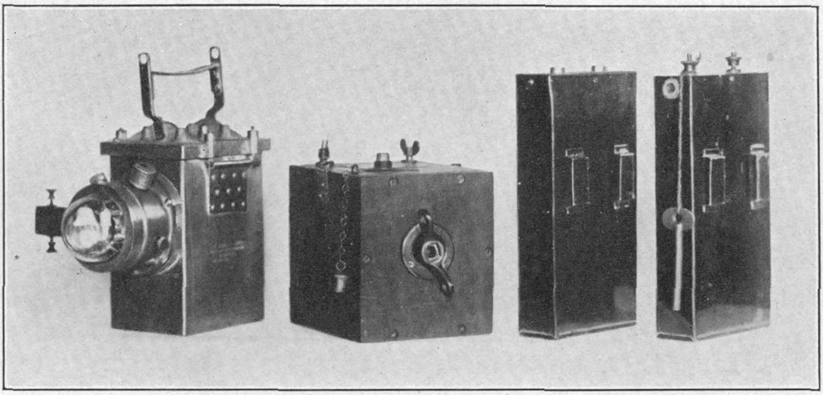
Dry cells.

Firing charges of explosives by means of ordinary dry cells has been prohibited in foreign countries, because premature firing of detonators, and sometimes of the charge, has been caused by the wires coming into contact with the poles of the batteries. Safety-contact dry-cell batteries have lately been introduced abroad and in this country. These are made with a spring-key contact, or with two safety-spring contact buttons, which are the poles of the battery. The two leading wires are laid on the buttons, which are at the same time pushed downward. When the pressure of the thumbs is released the contact is broken. If the wires of a detonator accidentally come into contact with the poles of the battery, the current can not be discharged unless both poles are pushed downward.

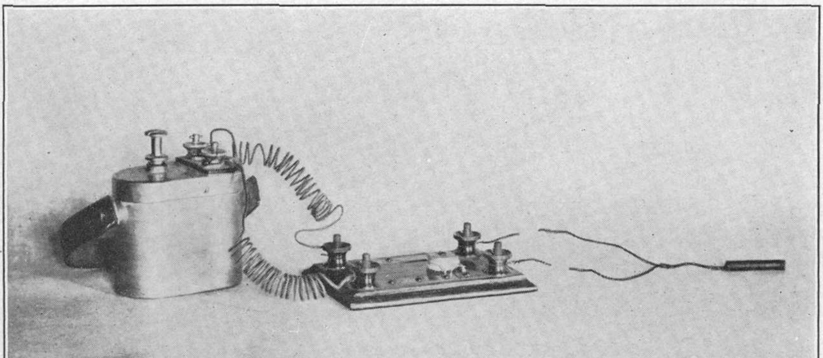
Dry cells, small batteries, and some firing machines can be carried about by the miner who is to act as shot firer, and this is an advantage



A. FUSE AND DETONATOR FITTED INTO PRIMER.



B. SECONDARY BATTERY, FIRING MACHINE, AND DRY CELL.



C. TESTING DETONATOR.

that insures him against premature firing by any other person.

Portable devices.

Such small devices can at best be used with only a few shots in one circuit. The number of shots to be fired and the length of leading wires and other conductors through which the firing is to be done must be known beforehand, so that a battery of sufficient capacity can be selected. Batteries often fail to fire blasts because they can not send such a current as will fire through the great length of leading wires, connectors, and detonator legs that is used for the blast.

Testing strength of batteries.

A simple way to test the strength of the batteries is to pass the current through a small electric lamp of known capacity and note the brightness of the light given by the lamp. Another way is to pass the current from the battery through a testing circuit whose resistance is equal to that of the circuit of a blast and which has in it one electric detonator. If the battery fires this detonator (which should be put in a safe place) it is strong enough and in good condition.

Firing from electric-lighting circuit.

When the electric current for firing is obtained from an electric-lighting circuit the connections are usually made in parallel; that is, one leg of every detonator is connected to one of the leading wires and all the other legs to the other leading wire. Care must be taken, by the use of insulating tape, that there shall be no short-circuiting in these connections.

Connecting up in parallel.

This method has the advantage that if there is a defective electric igniter or electric detonator in the circuit its failure will not prevent the rest of the blast from being fired; but, on the other hand, this method is objectionable because at any time after the explosion of the good igniters or detonators the unexploded charge with the defective igniter or detonator may be blown out and scattered in the coal, or it may even be set afire or perhaps exploded in the air of the mine by shock or friction. Furthermore, in this and other methods of electric firing an accidental premature blast may possibly be caused by leakage from the electric main to the earth and through the leading wires or connections, which may have become bared by rough handling or may not have been properly covered by the insulating tape. Premature explosions have been known to occur that were caused by leakage due to defective insulation.

Premature electric firing.

Dynamo-electric machines.

Firing machines, sometimes called blasting machines, generate the electric current to be used in firing by mechanical means. A variety of such machines have been invented, but the two best-known classes are the dynamo-electric machines and the magnetos. The dynamo-electric machines are made like ordinary dynamos used for generating electric currents, differing only in that they are worked by hand. They contain a coil-wound armature which is rotated between the poles of an electromagnet. This armature can be made to revolve by means of a crank or a vertical ratchet geared direct to the spindle of the armature. The machines with ratchet bars are made so as to store up the current during a stroke, until just as the stroke is ended the entire current that has gathered is discharged through the leading wires.

Rating of dynamo-electric machines.

These machines are built in different sizes and are rated according to the number of electric detonators they can fire. Thus, a "50-hole" machine will, when properly worked, fire 50 detonators at one discharge. The machines usually built for use in coal mines are rated as "4-hole" machines, and such a machine can be conveniently carried about by the miner or shot firer.

Magnetos.

The magneto machines consist mainly of an armature revolving between the poles of a set of permanent magnets. They look much like the dynamo-electric machines that are worked by cranks, and they are used in much the same way. These magneto machines are used to a considerable extent in foreign countries, but the "push down" dynamo-electric machine is the one most commonly used in the United States.

Leading wires.

The leading wires that carry the current from the blasting machine to the blast hole are of insulated copper wire, copper being used because it is one of the best conductors of electricity known and has the further advantage of being but little corroded in damp mines. These leading wires or firing lines are insulated with a braided covering, which is better if made waterproof. In some instances the two wires are twisted together and wrapped with an additional coating of braid, making them into one cable, which has the advantage of being more easily handled than two separate leading wires, and has also the advantage of the added protection given by the additional braiding.

Insulation of leading wires.

Inspection and repair of leading wires after firing.

After the blast has been fired, the ends of the leading wires should be immediately disconnected from the posts of the firing machine, and the lines should be examined for their whole length in order to see that the insulation has not been broken by coal or rock thrown against it, nor been stripped by the force of the blast. Where such defects or injuries are found, they should at once be repaired with insulating tape, and then the leading wires should be placed where they are not liable to injury until they are again needed.

Testing the line.

For testing the line after it is connected up, and before the firing, in order to show that the circuit is complete and that there is no leakage in the wires, a special galvanometer may be used, together with a battery such as many of the manufacturers of explosives now sell. This galvanometer, like others, bears upon its face a needle, which is turned or deflected if an electric current is present. By noting whether this needle is deflected or not one can tell whether the circuit is closed or open, and the extent of the deflection shows just how little resistance there is in the circuit. To use the galvanometer, the wires leading from it are connected to the two binding posts of the firing machine, to which the wires leading to the charge have already been connected. The deflection may then be noted. The current generated by the very weak battery cell attached to the galvanometer should not be strong enough to fire the electric detonators used in the bore holes, but is enough to deflect the galvanometer needle. This testing galvanometer, with its attached battery, should never be applied directly to the face to be blasted, even when it is being used to find out, when the test has shown no current, which of the electric igniters or electric detonators are defective. The tests for the separate detonators or igniters should always be made through leading wires long enough to let the person making the test stand where he would be perfectly safe if the blast should be fired; and on no account should this testing of the igniters or detonators be made while any person is so near that he may be in danger from the blast. (See Pl. IX, *C*.)

Use of galvanometer.

Safety precautions to be taken.

EXPLOSIVES IN SINKING SHAFTS AND BLASTING ROCK AND DIRT.

The use of any explosives other than permissible explosives is not recommended in any coal mine or part of a coal mine except in early development work, such as shaft sinking or entry driving through rock strata. In such work all men should be out of the shaft or working place when shots are fired.

Difference in conditions.

After the coal has been reached and it has become necessary that shots shall be fired while men are in the mine, permissible explosives only should be used. After a mine has been opened up, if rock or dirt is encountered, which may happen because of a fault or some other cause, it is quite necessary that permissible explosives be used, for it is known that inflammable gas is likely to be found in such places.

In the sinking of shafts or in the removal of rock or dirt by means of explosives, the methods to be followed in loading, tamping, and firing the charges of explosives are similar to those described for use in blasting coal. In this, as in other work, electric firing will be found to be the safest means of shot firing, and in the long run the cheapest.

Loading, tamping, and firing.

Tamping high explosives.

It is not uncommon to hear the statement that high explosives, because they are quicker in action than low explosives, need not be tamped. This is a serious error. The fallacy of it has been repeatedly proved in the tests of many different explosives made at the Pittsburg testing station. It has there been clearly shown that the highest pressure an explosive can give, and therefore the greatest amount of energy it can set free, will be developed only when the explosive is confined in the smallest possible space. Hence after the charges have been loaded into the bore holes they should be tamped with such materials (the best being damp clay) as confine the charges most closely, and this material should be rammed in firmly, with the precautions already set forth, quite to the mouth of the bore hole.

Proper strength of detonators.

In the appendix setting forth the test requirements for permissible explosives (p. 61) it is stated that electric or other detonators containing not less than 1 gram of the fulminating composition should be used in firing the charges. For use with high explosives in rock blasting, detonators of that strength are also best. Under no circumstances should an electric or other detonator be used of less strength than No. 5, containing 0.8 gram of the fulminating composition. The greater efficiency and certainty of the stronger detonator more than make up for its slightly greater cost.

Firing shots in groups.

In the sinking of shafts, after the soil has been removed and the overlying layers of shale and rock are uncovered, it becomes necessary to use explosives; and because in such a place the ventilation is always poor and the miner must wait for the fumes and smoke to clear away after each blast before he can safely return to his work, time can usually be saved by firing shots in groups instead of singly. Dynamite, or, when the shaft is wet, gelatin dynamite, may be used for these shots, which should always be fired after the men are out of the shaft. The most economical and safest way of firing a number of shots at one time is by means of the electric current, with electric detonators. The older method of firing by fuse is dangerous and wasteful. Where fuse is used, there is always danger that a seeming misfire may prove to be a hang fire—that is, the smoldering fuse may cause the charge to explode unexpectedly. Also, if by any chance there is any irregularity in the burning of the fuse, the miner can not properly judge the time necessary to get out of the shaft and out of danger after having lighted the fuse.

Firing simultaneously.

In shafts that run through rock, as most shafts do, there is no objection to the shattering effect of firing several shots at the same instant, and this method is recommended; but when it happens that in shaft sinking the shattering effect would be harmful, and successive shots are therefore to be used, it is still advised that they be fired by electricity. For such shots, however, a less violent explosive may be employed, and the delay-action electric detonator already described (p. 33) may be used to good advantage.

The following explosives may be recommended, in a general way, for use when the size and condition of the material resulting from the blast is not important, for example, in the sinking of shafts or the driving of entries through rock:

Various explosives for use in sinking shafts and driving entries.

For use where the texture of the material is very tough and hard, as in tough granite, hard bowlders, and the like, 60 per cent straight nitroglycerin dynamite is recommended. Where the material is of moderate toughness and somewhat brittle, 50 per cent straight nitroglycerin dynamite is recommended. In material such as limestone and sandstone, 40 per cent straight nitroglycerin dynamite is recommended. In hard earth or compact sand, a 30 to 20 per cent straight nitroglycerin dynamite is recommended. In material such as a soft crumbly or seamy rock that requires a stronger explosive than black blasting powder, but a slower explosive than dynamite, a granulated powder containing 5 per cent of nitroglycerin is recommended. This should always be fired with a priming stick of dynamite. With this exception, different kinds of explosives should never be used in the same bore hole.

For very soft work in cuts and fills, or for quarry work when dimension stone is sought, black blasting powder is recommended. In grading work the blast hole may be bottomed out with dynamite before charging with granulated powder or with black blasting powder, but before it is charged, care should be taken to see that the dynamite charge has not left any fire in the hole. In plastering or adobe work on bowlders and spawls, or in block holing, a strong dynamite should be used. Block holing is the more effective and economical method for use with bowlders.

Ammonia dynamites.

If the straight nitroglycerin dynamites, as recommended above, are found to be too quick or too violent for use, and the results obtained are not as desired under the given circumstances, ammonia dynamites, which give a more heaving and rending action, are recommended. They are made in several grades and are rated as of a certain percentage of strength, but this rating is not always made in a scientific way. The following composition is an example of that which is generally offered in this country as a 40 per cent strength ammonia dynamite:

Composition of 40 per cent strength ammonia dynamite.

	Per cent.
Nitroglycerin	22
Ammonium nitrate	20
Dope	58

This composition does not contain so large a percentage of nitroglycerin as the straight 40 per cent dynamite (see p. 19), and as tested at the Pittsburg testing station it is not found to produce the same results as the latter. Nevertheless the ammonia dynamites are often found to be more economical and more efficient for certain classes of work than the straight dynamites of the same commercial rating. The ammonia dynamites are less readily set off and are safer to handle, transport, and store than the straight dynamites are, but they all require stronger detonators than the straight dynamites to insure a complete and rapid detonation. They have the disadvantage, compared with the straight dynamites, of taking up moisture very readily, and great care should be used in storing them or in using them in wet holes.

Caution in use of ammonia dynamites.

Gelatin dynamites.

For use in very wet blasting and in places where there is poor ventilation the gelatin dynamites are recommended. Water has but little effect on them, and on complete explosion they yield only a small quantity of fumes and bad gases. Like ammonia dynamites, gelatin dynamites are less sensitive than straight nitroglycerin dynamites, and they therefore require stronger detonators to cause their complete explosion. They become less sensitive during long storage, and they have been known after long storage in tropical countries to become so insensitive that they could not be detonated by means of the devices ordinarily used in firing them. Gelatin dynamite is likely to decompose during storage in very hot places.

Like the ammonia dynamites, the gelatin dynamites are sold in several grades and are given a somewhat unscientific rating in commerce. The grade known as 40 per cent strength gelatin-dynamite, as generally offered in this country, has the following composition:

Composition of 40 per cent strength gelatin dynamite.

	Per cent.
Nitroglycerin	32
Soluble nitrocellulose	1
Dope	67

As tested at the Pittsburg testing station, gelatin dynamites have not been found to be equivalent in every respect to straight nitroglycerin dynamites of the same commercial rating, and as regards economy they should seldom be used as equivalent; but they are superior for some uses, as mentioned above.

SAFE SHIPMENT AND STORAGE OF EXPLOSIVES.

By B. W. Dunn.

Responsibility to public.

A responsibility to the public rests upon both manufacturers and common carriers to secure the safe delivery at destination of explosives, and it is the duty of the owners of explosives to store them safely.

Federal law and Interstate Commerce Commission regulations.

Under authority granted by Congress, the Interstate Commerce Commission has made regulations, binding upon shippers and common carriers, for the transportation of explosives in interstate commerce, and the penalty of a possible fine of $2,000 and eighteen months' imprisonment is prescribed by law for a violation of any of these regulations.

The shipper must know and certify on his shipping order that the explosive offered by him is in a proper condition for safe transportation and that it is packed and marked as required by the regulations. To perform this duty the shipper should be thoroughly familiar with all requirements pertaining to his shipment. A copy of the regulations can be obtained by application to the railway agent, whose duty it is to furnish them to shippers.

The following paragraphs in these regulations are of special interest to the shippers of explosives used in mines: *General Rule A.*—Paragraphs 1501, 1502, 1503, 1509, 1510, 1531, 1533, 1541 to 1556, 1558 to 1560, 1611 to 1614, 1648, 1661, 1665, 1666, 1668, 1674 to 1683.

Explosives in baggage or household goods.

Miners and other persons are sometimes tempted to pack explosives for shipment with their baggage on passenger cars, or with their household goods for shipment by freight. To do this is a criminal act that may endanger the lives of the innocent and unsuspecting persons who have to handle these packages, and that will subject the guilty shipper, when detected, to arrest and prosecution. The federal law (section 236) prescribes an imprisonment of ten years for anyone convicted of this crime when death or bodily injury results from the illegal transportation of explosives. When no injury results, the maximum penalty is eighteen months imprisonment and a fine of $2,000.

Magazine buildings.

There is no standard type of storage magazine in use in this country, and the laws and regulations in foreign countries applicable to the construction of magazines differ materially. In Austria, for example, they are required to be of light construction, while in England they must have walls at least 18 inches thick.

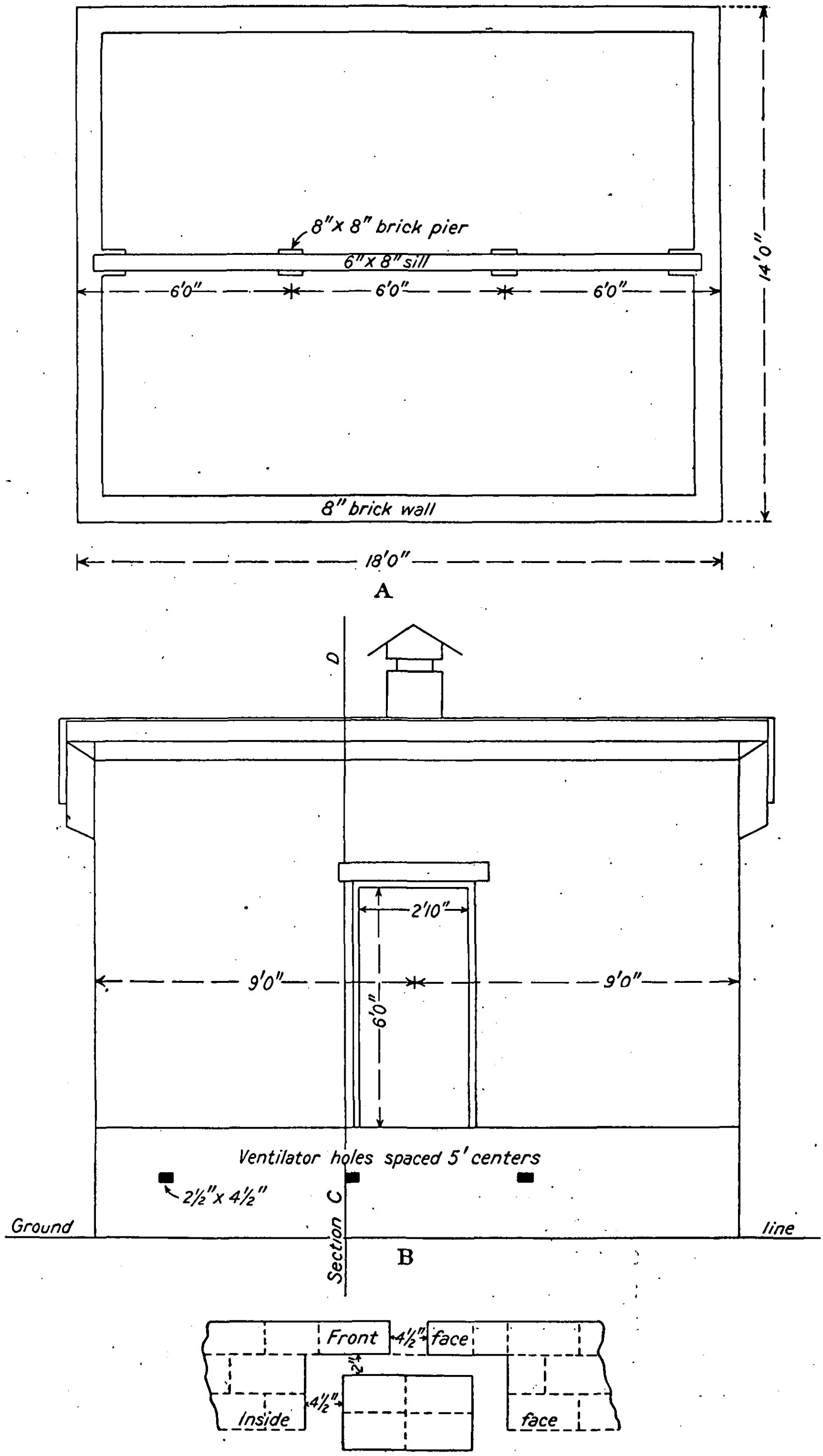


FIGURE 11.—Foundation plan (A), front elevation (B), and plan of ventilator hole (C) of brick magazine.

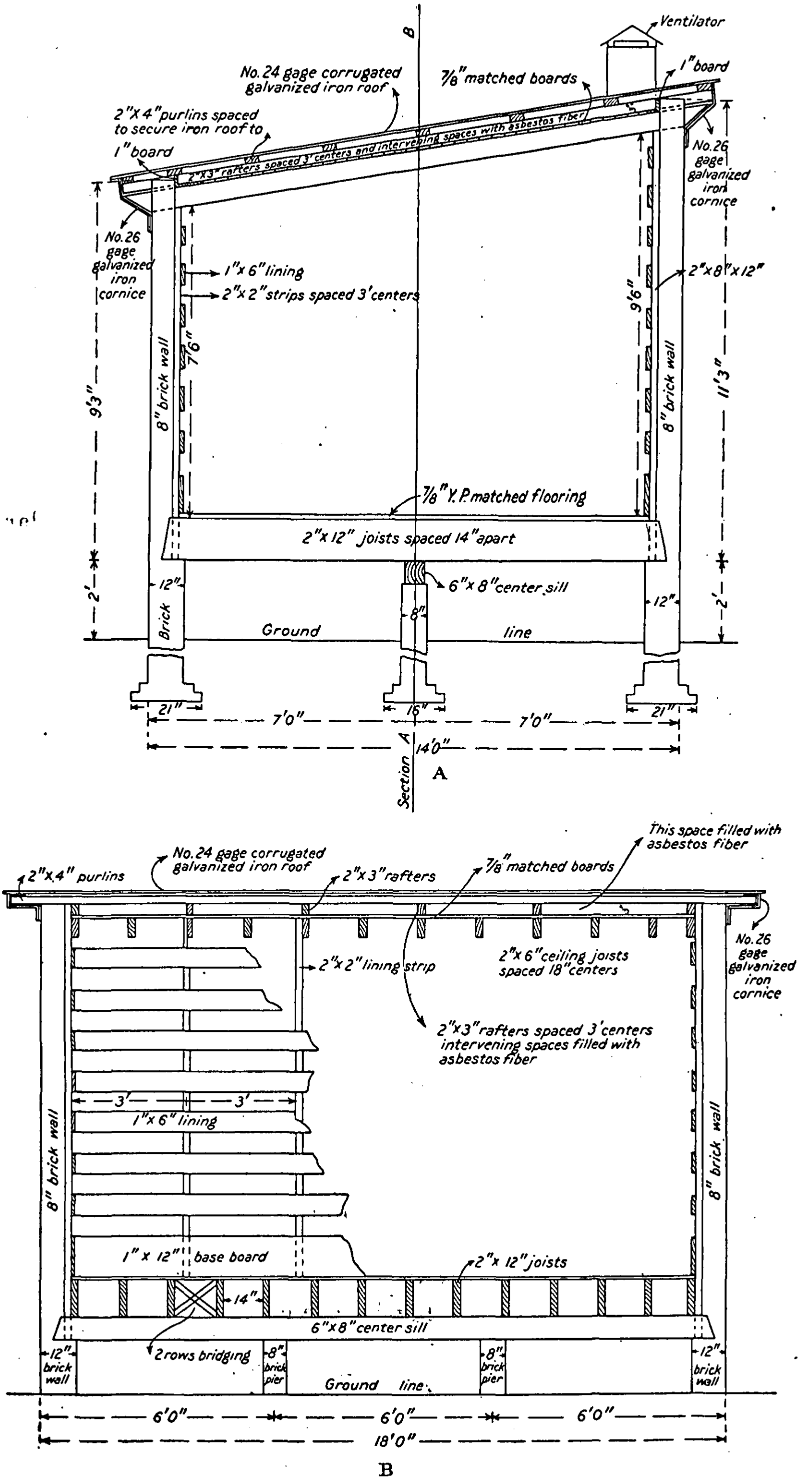


FIGURE 12.—Sections of magazine: A, section at line *CD* in fig. 11, B; B, section at line *AB* in fig. 12, A.

Explosives should be protected as far as practicable during storage against heat, moisture, fire, lightning, projectiles, and theft. The buildings should therefore be weatherproof, covered by fireproof and bullet-proof material, well ventilated, in secluded locations, and not beside grass or underbrush subject to fire risk. Lightning protection is best placed on a line of supports encircling the building and 20 to 30 feet distant from it. Figures 11 and 12 show plans of an approved type of magazine.

Isolation of magazines.

It is difficult to state definitely safe distances to separate magazines from dwellings, highways, railroads, etc. The proper distance must vary, evidently, with the amount of explosives stored and the degree of natural protection afforded by the slope of the ground and of artificial protection, such as barricades or mounds of earth.

The distances prescribed by the English law have been adopted by the State of Massachusetts. They are materially greater for large quantities of explosives than those prescribed in other countries. For example, the distances from a railway or public highway prescribed for a magazine containing explosives without natural or artificial protection are: For 1,000 pounds—England, 630 feet; Prussia, 984; Austria, 984; Italy, 244; for 10,000 pounds—England, 795 feet; Prussia, 1,968; Austria, 1,640; Italy, 328; for 80,000 pounds—England, 2,160 feet; Prussia, 1,968; Austria, 984; Italy, 574.

These distances may be materially reduced, in some places to one-half or even to one-quarter, where there is good natural or artificial protection.

Care of magazines.

Magazines should be kept clean and in thorough repair. Grounds around them should be kept clear of leaves, grass, or other materials that might feed a fire. These words should be conspicuously posted on them: "Explosives—dangerous. No shooting allowed." The floors must be swept regularly and kept clean. The sweepings should be thrown in water or taken to a safe distance and destroyed.

In case floors become stained with nitroglycerin, cover the stains with dry sawdust, sweep up, and remove the sawdust. Then scrub the stains thoroughly with a hard brush and a solution of one-half pound of sulphide of sodium or sulphide of potassium in one-half gallon of wood alcohol.

Do not allow in the magazine any tools other than a wooden mallet and wooden wedge, or a phosphor-bronze chisel, and a screw-driver to be used only for removing screws.

Do not open dynamite boxes with a nail puller or powder cans with pickaxes.

Remove all explosives before repairing a magazine.

Do not store detonators with explosives, especially high explosives.

Do not open packages of explosives in a magazine.

Issue first the oldest explosives on hand.

Do not store dynamite boxes on end, as this increases the danger of nitroglycerin leaking from the cartridges.

Persons receiving packages of explosives sent by rail should examine them carefully to discover ruptures or other serious damage during transit. Any information regarding such matters will be welcomed by the Chief Inspector, Bureau for the Safe Transportation of Explosives, 24 Park place, New York City.

APPENDIX.

U. S. GEOLOGICAL SURVEY TEST REQUIREMENTS FOR EXPLOSIVES.

The tests will be made by the engineers of the United States explosives testing station at Pittsburg, Pa., in gas and dust gallery No. 1. The charge of explosive to be fired in tests 1, 2, and 3 shall be equal in disruptive power to one-half pound (227 grams) of 40 per cent nitroglycerin dynamite in its original wrapper, of the following formula:

Nitroglycerin	40
Nitrate of sodium	44
Wood pulp	15
Calcium carbonate	1
	100

Each charge shall be fired with an electric detonator of sufficient power to completely detonate or explode the charge, as recommended by the manufacturer. The explosive must be in such condition that the chemical and physical tests do not show any unfavorable results. The explosives in which the charge used is less than 100 grams (0.22 pound) will be weighed in tinfoil without the original wrapper.

The dust used in tests 2, 3, and 4 will be of the same degree of fineness and taken from one mine, to insure uniformity of composition and inflammability.

Test 1.—Ten shots with the charge as described above, in its original wrapper, shall be fired, each with 1 pound [a] of clay tamping, at a gallery temperature of 77° F., into a mixture of gas and air containing 8 per cent of methane and ethane. An explosive will pass this test if all 10 shots fail to ignite the mixture.

Test 2.—Ten shots with charge as described above, in its original wrapper, shall be fired, each with 1 pound [a] of clay tamping, at a gallery temperature of 77° F., into a mixture of gas and air containing 4 per cent of methane and ethane and 20 pounds of bituminous coal dust, 18 pounds of which is to be placed on shelves laterally arranged along the first 20 feet of the gallery, and 2 pounds to be placed near the inlet of the mixing system in such a manner that all or part of it will be suspended in the first division of the gallery. An explosive will pass this test if all 10 shots fail to ignite the mixture.

Test 3.—Ten shots with charge as described above, in its original wrapper, shall be fired, each with 1 pound [a] of clay tamping, at a gallery temperature of 77° F., into 40 pounds of bituminous coal dust, 20 pounds of which is to be distributed uniformly on a horse placed in front of the cannon and 20 pounds placed on side shelves in sections 4, 5, and 6. An explosive will pass this test if all 10 shots fail to ignite the mixture.

Test 4.—A limit charge will be determined within 50 grams by firing charges in their original wrappers, untamped, at a gallery temperature of 77° F., into a mixture of gas and air containing 4 per cent of methane and ethane and 20 pounds of bituminous coal dust, to be arranged in the same manner as in test 2. This limit charge is to be repeated five times under the same conditions before being established.

Subject to the conditions named below, a permissible explosive is defined as an explosive which is in such condition that the chemical and physical tests do not

[a] Two pounds of clay tamping are used with slow-burning explosives.

show any unfavorable results, which has passed gas and dust gallery tests Nos. 1, 2, and 3 as described above, and of which in test No. 4 the limit charge has been established at or above 1½ pounds (680 grams).

Provided: 1. That the explosive is in all respects similar to the sample submitted by the manufacturer for test.

2. That No. 6 detonators, preferably No. 6 electric detonators (double strength), are used of not less strength than 1 gram charge, consisting by weight of 90 parts of mercury fulminate and 10 parts of potassium chlorate (or its equivalent), except for the explosive "Masurite M. L. F.," for which the detonator shall be of not less strength than 1½ grams charge.

3. That the explosive, if frozen, shall be thoroughly thawed in a safe and suitable manner before use.

4. That the amount used in practice does not exceed 1½ pounds.

SURVEY PUBLICATIONS ON MINE ACCIDENTS AND EXPLOSIONS.

The following publications, except Bulletin 369, can be had free by applying to the Director, U. S. Geological Survey, Washington, D. C. Bulletin 369 can be had by sending the price, in cash, to the Superintendent of Documents, Government Printing Office, Washington, D. C.

Bulletin 333. Coal mine accidents: their causes and prevention—a preliminary statistical report, by Clarence Hall and W. O. Snelling, with introduction by J. A. Holmes. 1907. 21 pp.

Bulletin 369. The prevention of mine explosions. Report and recommendations, by Victor Watteyne, Carl Meissner, and Arthur Desborough. 1908. 11 pp. 5 cents.

Bulletin 383. Notes on explosive mine gases and dusts, with special reference to the explosions in the Monongah, Darr, and Naomi coal mines, by R. T. Chamberlin. 1909. 67 pp.

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