MANUAL
OF
EXPLOSIVES

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A BRIEF GUIDE FOR THE USE OF MINERS AND QUARRYMEN

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ISSUED BY
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ANNOUNCEMENT.

The growth of the mining industry in Ontario, and the number of casualties which have occurred owing to the careless or ignorant use of explosives employed in the industry, have suggested the need of a book of instructions on the safest methods of handling the materials, both in transportation and at the mines. It is also desirable, where men have not acquired experience, that hints should be given on the best means of using explosives to obtain the largest economic results. Safety and efficiency are the two chief objects aimed at in the Manual which Prof. De Kalb has been authorized by the Commissioner of Crown Lands to prepare. His own experience in practical mining, his training as a mining engineer, and his knowledge of the conditions which exist in Ontario acquired in the inspection of mines, have commended him for the task of writing on the subject of explosives, and it is hoped that the Manual will serve a useful purpose. It is issued by the Bureau of Mines for presentation to all mine managers in the Province, as well as to foremen and others who have charge of operations with explosive materials.

ARCHIBALD BLUE.

BUREAU OF MINES,
TORONTO June, 1900.

LETTER OF TRANSMITTAL.

Mr. Archibald Blue,

Director of the Bureau of Mines,

Toronto, Ontario.

Dear Sir :

In compliance with your instructions I have prepared, and beg to submit, the following pages on the nature and proper methods of handling of explosives. The matter herein presented is in part a compilation from the literature on explosives, and in part the result of direct inquiry from well-known authorities on the subject. To a certain extent I have drawn from my own experience in the practical use and testing of explosives.

I have the honor to be,

Your obedient servant,

COURTENAY DE KALB.

School of Mining,
Kingston, May 15, 1900.

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PREFACE.

In spite of the enormous quantities of explosives which are consumed in modern engineering operations, there exists a very imperfect knowledge of their character and qualities on the part of the general public. Not only does this entail great risk to life and property from the incautious use of these powerful agents of destruction, but their employment by men ignorant of their proper application for the performance of specific work under varying conditions leads to important waste of material. If a charge of dynamite or other high explosive is so fired as to produce only 75 per cent. of its possible useful effect, there has resulted both a loss of available energy and a waste of a certain portion of the time, labor and power expended in preparing for the blast. The aggregate unproductive expenditure appears as a first charge against the ore or rock extracted.

In such a brief survey of the subject as is here contemplated it will be impossible to lay down rules which will enable one to employ explosives always with safety and to the highest economic advantage, but it may serve to correct many erroneous impressions and to point out the way to a better use of blasting agents. For those who wish to acquire further information on the characteristics of explosives, and the proper application of them in industrial work, a list of valuable treatises is given at the end of this Manual.

The immediate cause of the preparation of this manual has been the alarming increase in the number of fatal accidents with explosives occurring throughout the Province during recent years. In consequence, particular stress will be laid on precautionary measures to insure greater safety. It would seem almost unnecessary to warn intelligent human beings against the perils of warming dynamite over an open fire, of carrying it in their bootlegs, of throwing pieces of dynamite cartridges into out-of-the-way corners of a mine where they may be discovered with painful results in future ; nor would it seem needful to point out the terrible disaster that may follow from biting a cap on to a fuse. But these and equally reckless practices are of daily occurrence at mines and on railroads, entailing risk of life not only to those who themselves are guilty of such criminal carelessness, but, what is worse, to innocent parties who may chance to fall victims to the consequences of the act.

Special acknowledgment is due to Dr. Charles E. Munroe of Washington, D.C., for valuable suggestions and generous aid in facilitating the preparation of this little guide, and the author desires furthermore to express his sense of indebtedness to the late Mr. Addison C. Rand of New York for much practical assistance.

CHAPTER I.

COMMON EXPLOSIVES.

The explosives in common use in America are very few. Practically the average foreman is acquainted with only two kinds, black powder (gunpowder and blasting powder), and some of the ordinary varieties of dynamite on the market. The number of explosive compounds recognized in Europe runs high into the hundreds, but for the most part their introduction into American practice has been slow and financially unsuccessful. Many of these possess great merit, and deserve a cordial reception by mine managers and quarrymen. To find such conservatism toward improvements in blasting powders on this side of the Atlantic is a little surprising. The only explanation would seem to be that dynamite is reasonably safe, is nearly as efficient as the best of these new compounds, and is sold at a lower cost than is possible with the most of its competitors. That there are explosives, however, which are superior in point of safety to dynamite, and which will yield better economic results in the long run when intelligently applied, is undeniable. But so much better results can be obtained with our old familiar explosives than are generally obtained to-day, that it is chiefly desirable to improve upon our present methods.

According to the British Explosives Act of 1875, all explosives are divided into seven classes, viz. ; 1, Gunpowder; 2, Nitrate Mixture; 3, Nitro-compound; 4, Chlorate Mixture; 5, Fulminate; 6, Ammunition; 7, Fireworks.

This is largely arbitrary, and while serviceable for administrative purposes is not scientifically exact. Among manufacturers of explosives the following classes are generally recognized; 1, Explosive Mixtures of the Nitrate class; 2, Explosive Mixtures of the Chlorate class; 3, Explosive Compounds of the Nitro-substitution class; 4, Explosive Compounds of the Nitric derivative class; 5, Explosives of the Sprengel class; 6, Fulminates and Amides.

1. Explosive Mixtures of the Nitrate Class.

The best known example of this class is gunpowder. The characteristic of these explosives is that they consist of a mechanical mixture of nitrates with some base containing charcoal or other substance yielding carbon. The nitrates carry the oxygen which combines with the base under favorable circumstances, developing a large volume of gases at a high temperature, so that if the powder is confined at the time of explosion there will be produced an enormous expansive effort.

The standard composition of gunpowder is

Potassium nitrate (nitre or saltpetre)	75 parts.
Charcoal	15 "
Sulphur	10 "
	100

The charcoal employed for military and sporting powder is made commonly from dogwood, while for blasting powder willow and alder are used. In some inferior powders lampblack is substituted in part for charcoal, and in a few brands of special powders lignite, coal and various forms of carbohydrates are employed. In one interesting military explosive, viz., cocoa powder, the carbonaceous residue remaining after extracting the soluble matter from rye straw with superheated steam is used instead of ordinary charcoal.

Nitre is generally superior to other nitrates, mainly on account of its failure to deliquesce, that is, to take up moisture from the atmosphere. In this respect barium nitrate is superior, but its cost is high, and the resultant powder is too slow in its action for ordinary purposes. Sodium nitrate is exceedingly deliquescent, and yields a powder which tends to deteriorate rapidly under the influence of moisture. It is never introduced into any but blasting powders, and those containing it should be used while the powder is as fresh as possible, and they should be protected from dampness with great care. It is claimed for them that their action is more powerful for a given weight, on account of the larger amount of available oxygen in sodium nitrate than in an equal weight of potassium nitrate (nitre). Other forms of blasting powders which have been put on the market at various times may be represented by the following: Carbo-azotine, containing

Potassium nitrate	70
Sulphur	12
Lampblack	5
Sawdust	13
Ferrous sulphate	2

And Pyrolithe, claimed to produce no carbon monoxide during explosion, which, if true, should cause the development of greater power. This contains

Potassium nitrate	51.50
Sodium nitrate	16.00
Sulphur	20.00
Sawdust	11.00
Charcoal	1.50

Properties of Gunpowder. The proper color of good gunpowder or blasting powder is a uniform dark gray or slaty hue. A dead black or decidedly bluish color indicates either the presence of too much charcoal or an excess of moisture. It should show no difference in color when crushed, and no sharp or angular fragments should be visible before crushing. On pressing the powder between the fingers it should not crackle, nor should it crush easily by such pressure. It should not crumble under this test, but fall to pieces in angular fragments. The size of grains should be quite uniform, and there should be no dust when new. It should leave no color when poured over the hand or a sheet of paper, which would indicate the existence of meal powder or too much moisture. Single bright spots, or bluish-white spots, show that the powder has been damp, causing efflorescence of the saltpetre, which destroys the uniformity of composition of the explosive and renders its action unreliable. As a rule powder has not suffered materially from dampness if no efflorescence of saltpetre has taken place. Damp powder can be restored by drying it in the sun, or in a well ventilated room.

Good gunpowder should have a specific gravity somewhere between 1.5 and 1.85. The value of the powder, other things being equal, varies with its specific gravity; the denser it is the more powerful. No simple test, however, as to this property can be made by the ordinary consumer of blasting powder.

A blow of copper on wood rarely explodes gunpowder, a blow of wood on wood never, but a blow of copper or wood on stone has frequently exploded it, especially in ramming it into holes with wooden rammers, when the rammer was struck too violently by a hammer. The ignition temperature of blasting powder is 518° F., and of rifle powder 528.8° F. The finest grades of sporting powder ignite at about 600° F. Burning bodies only ignite gunpowder when they are very hot This is well shown in attempting to ignite blasting powder with a match. As long as there is an ordinary flame the powder will not ignite, but as soon as a narrow pointed flame issues it ignites instantly. A gas flame will only ignite powder after it has acted upon it for a few seconds.[1] Sparks from steel or stone ignite powder easily. An electric spark ignites powder only when the discharge is delayed by the interposition of a bad conductor. An electric current will explode gunpowder only through the heating of a resistance wire in the circuit. Good black powder ignited on a piece of white paper burns away rapidly, leaving no residue. If black spots be found they indicate excess of charcoal, or imperfect mixture of the ingredients of the powder. Yellow spots remaining on the paper indicate excess of sulphur; and if any holes

1 Oscar Guttmann, "The Manufacture of Explosives," vol. i. p. 332.

have been burned in the paper it indicates excess of moisture, or some other imperfection in the powder.

2. Explosive Mixtures of the Chlorate Class.

In explosives of this class the oxygen for combustion is present in the well-known compound, chlorate of potash. A mixture of this salt with almost any carbonaceous material will explode under suitable, and often unexpected, circumstances. The tendency of chlorate mixtures to explode under slight friction, or even without any apparent cause, is so great that they have not come into general use except in fuse compositions and in detonators. Almost none of the patented explosives of this class have stood the test of the British Inspectors, only three such explosives having been accepted, and only one of these, asphaline, having been licensed. It consists of thoroughly cleansed wheat or barley bran, impregnated with potassium chlorate, mixed with potassium nitrate and sulphate. The proportions of these ingredients are stated to be:

Potassium chlorate	54 parts
Bran	42 "
Potassium nitrate Potassium sulphate	4 "

The chlorate mixtures will not concern the miner or contractor, and they may be dismissed with a quotation from Dr. Duprè, F.R.S., who says:

"Chlorate of potassium, on account of the readiness with which it lends itself to the production of powerful explosives, offers a great temptation to inventors of new explosives, and many attempts have been made to put it to practical use, but so far with very limited success. This is chiefly owing to two causes. In the first place potassium chlorate is a very unstable compound, and is liable to suffer decomposition under a variety of circumstances, and under comparatively slight causes, chemical and mechanical. All chlorate mixtures are liable to what is termed spontaneous ignition, or explosion, in the presence of a variety of materials, more particularly of such as are acid, or are liable to generate acid ; and all chlorate mixtures are readily exploded by percussion, such as a glancing blow which might easily and would often occur in charging a hole. In the second place there is some evidence to show that the sensitiveness to percussion and friction increases by keeping, more especially if the explosive is exposed to the action of moist and dry air alternately."

Its extreme sensitiveness may be illustrated by the circumstance that chlorate of potash tablets for the throat have been exploded with great violence by replacing a watch into a vest pocket containing a few of them.

3. Explosive Compounds of the Nitro-Substitution Class.

The essential difference between an explosive compound and an explosive mixture is that in the latter a number of separately existing chemical substances capable of reacting and producing a large volume of gases at a high initial temperature, are intimately mixed by mechanical means, while in the case of explosive compounds we are dealing with a single chemical substance containing oxygen and other elements capable of uniting therewith to form stable gases at a high temperature. The explosion is accomplished by a dissociation of the elements constituting the compound, and by their recombination into a variety of gaseous compounds. The modern high explosives consist of such explosive compounds, either used pure, or mixed with other substances which serve to reduce the risk of their accidental explosion, and to so modify their action as to adapt them to the requirements of different classes of work.

The nitro-substitution compounds are formed by "nitrating" certain hydrocarbons of the aromatic series, which for the most part are coal tar products. The commonest products which are thus employed are phenols (carbolic acid), benzenes, naphthalenes and toluene. The process of nitration consists in introducing into the molecule of the original hydrocarbon a certain quantity of nitrogen and oxygen, by treating it with nitric acid, thus making a new chemical compound, relatively unstable, and containing the necessary elements to produce fixed gases at high temperature as stated above

The treatment of "carbolic acid," or phenol with nitric acid yields picric acid, a yellow crystalline compound having explosive properties which under favorable circumstances may assume violent proportions. Some of the more recent explosives used for charging shells in warfare, such as lyddite, are nothing more than fused picric acid. A mixture of this substance with sodium nitrate and potassium chromate, known as Borlinetto's powder, is an extremely sensitive and powerful explosive. It contains

Picric acid	10 parts
Sodium nitrate	10 "
Potassium chromate	8.5 "

Common potassium carbonate, stirred into a boiling solution of picric acid in water, yields crystals of potassium picrate, one of the most sensitive explosive compounds known. When mixed with potassium chlorate its explosive violence equals that of nitroglycerine, with the disadvantage of being infinitely more unstable and sensitive. A large number of explosives have been patented consisting essentially of the nitro-substitution compounds, many of which are unsuitable for economic purposes on account of their high cost and dangerous character, while others are equally remarkable as being among the less expensive high explosives, and unequalled for their extraordinary freedom from accidental explosion under the circumstances that ordinarily determine such catastrophes. One of the most remarkable of these is bellite, invented by Carl Lamm of Stockholm, Sweden, consisting of 5 parts of ammonium nitrate and 1 part of meta-di-nitrobenzene, melted together, into which potassium nitrate is then stirred. It may be molded into cartridge form, or cooled and granulated, forming a free running powder like gunpowder. As this explosive is not now on the market, its price being prohibitive, it may be best to state its peculiar properties in connection with another explosive known as joveite, which it resembles closely, this latter being manufactured in the United States and sold at prices competing with dynamite.

Joveite is made in three grades, having the following compositions:

	No. 1	No. 2	No. 3
Nitro-naphthalenes.......	8 per cent.	8 per cent.	6 per cent.
Nitro-phenols	16 "	25 "	30 "
Nitrate of soda	76 "	67 "	64 "

Of these grades No. 3 is the quickest and most powerful, and No. 1 the slowest, being about equivalent to low grade dynamites in power. It presents no danger in its manufacture. It will not explode from friction, shock or pressure; fire, lightning, or electric sparks. It can only be exploded with detonators ("exploders") such as are used in exploding dynamite. It undergoes no chemical change from age or from atmospheric influences. It is unaffected by tropical heat, or the extreme cold of winter. It does not freeze, but can be used at all normal temperatures. Its products of explosion contain no noxious gases, so that it is peculiarly adapted to operations underground. Its explosive temperature is 536° F. When ignited in the open it burns vigorously, but does not explode. It has been tested by the ablest explosive experts and has never proven unsafe or unreliable. It would seem to fulfil all the requirements of an ideal explosive.

Securite is an explosive very similar to bellite, having all its advantages, with the disadvantage of the cost due to the ammonium nitrate used. A variety of securite containing ammonium oxalate is said to be flameless.

A class of these explosives which has had considerable acceptance abroad is known as the Volney powders, named after the inventor, C. W. Volney. They consist of nitro-naphthalenes mixed with saltpetre and sulphur. The higher the degree of nitration the less of the nitrate mixture is required, and the higher is the breaking power of the explosive. The powders can thus be graded to meet the conditions of blasting in hard, or in soft and fissured rocks. They are very insensitive to friction, or shock, and are no more liable to accidental explosion than gunpowder. Judging from the ingredients used it would not seem that their cost should be prohibitive.

Ammonites, or Favier explosives, are well known blasting agents of the nitro-substitution class, which have been extensively used abroad, particularly in France. While the different grades vary considerably in composition, the type of the Favier explosive may be represented by the formula

Ammonium nitrate	90 per cent.
Nitro-naphthalene	10 "

The nitro-napthalene is melted and the ammonium nitrate then incorporated with it. Each of these substances alone is very stable, and absolutely safe. When mixed they will still resist rough usage, and will not even explode with the ordinary detonator, requiring a cap containing 1 gramme of fulminate of mercury to effect detonation.

Other explosives of the same class are emmensite, gelbite and roburite. The latter was the invention of

Dr. Carl Roth, and it is claimed that by introducing chlorine into the nitro-compound a more powerful explosive was produced, exceeding dynamite in this respect, while producing a rending instead of a shattering effect. It consists essentially of nitrate of ammonium with thoroughly purified chlorinated di-nitrobenzole. Its insensitiveness is very marked, it does not freeze, and it is claimed to be practically flameless. It requires a powerful detonator to explode it. Roburite is manufactured and extensively used in Great Britain. The nitro-substitution powders which have attained an economic importance have collectively acquired the name of "safety explosives," on account of their peculiar properties, and their industrial application will undoubtedly steadily increase in future.

4. Explosive Compounds of the Nitric Derivative Class.

The two explosives of the nitric derivative class which are generally known are guncotton and nitroglycerine, with special preparations made from them, such as dynamite, blasting gelatine, etc. Chemically considered they are nitric derivatives from alcohols, just as the nitro-substitution explosives were nitric derivatives from the aromatic series of hydrocarbons. A marked distinction between them is that when the nitro-substitution compounds are treated with alkalies nitric acid is not reproduced, but various nitrogenous substances are formed, and when subjected to the action of reducing agents the result is the formation of amides. By treating nitric derivatives, however, with reducing agents the original ingredients may be reproduced either wholly or in part, according as the derivative is a nitric ether or a nitric ester.[2] Guncotton is the representative of the nitric esters, made by the action of nitric acid on a complex alcohol, while nitroglycerine is the representative of a nitric ether, produced by the action of nitric acid on a simple alcohol. For a general discussion of the chemistry of these interesting bodies the reader is referred to the works of Guttmann, Walke, Berthelot, Chalon and Von Romocki.

Guncotton is made by treating suitably prepared cotton with a mixture of 1 part by weight of nitric acid (1.5 sp. g.) and 3 parts of sulphuric acid (1.85 sp. g.). The immersion lasts 48 hours, the temperature being maintained at 60°F. The cotton is then subjected to a thorough and prolonged washing, after which it is carried through various processes to prepare it for use. The cellulose of the cotton has thus been converted into tri-nitrocellulose. By varying the strength of the acids different degrees of nitration may be obtained. Guncotton is extensively employed for military purposes, but not for blasting. It constitutes however one of the ingredients, of blasting gelatine, and is the chief constituent in most so-called "smokeless powders."

Properties of Guncotton. Guncotton differs but slightly in appearance from ordinary cotton. It has a harsh feel, and is less flexible than common cotton. It becomes highly electrified when rubbed between the fingers, and

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[2] Lectures on Explosives by Willoughby Walke, 1897.

appears luminous when rubbed in the dark. It is entirely insoluble in hot or cold water, but dissolves in a mixture of ether and ammonia. It will rarely take up more than 2 per cent. of moisture from the atmosphere. It is insensible to pressure, percussion or friction, unless closely confined and firmly compressed. It burns with a flash, but without explosion, if brought into contact with a burning or incandescent body. Wet guncotton will not burn or explode. Its ignition temperature is 360°F. Pure guncotton will undergo no spontaneous decomposition, and is the safest explosive known. Although it will not explode when wet, it may be detonated when in this condition by a mercury fulminate detonator with a small initial charge of dry guncotton in contact with it. Under these circumstances it develops its maximum force in a minimum of time. Wet guncotton when detonated produces a more violently disruptive effect than if detonated dry.

Nitroglycerine is a nitric ether, or specifically a glyceryl tri-nitrate. Different degrees of nitration yield the mono-, di- and tri-nitroglycerine, respectively, the latter being the nitroglycerine of commerce, having the chemical formula $C_3H_5O_3(NO_2)_3$. It is made by treating an exceedingly pure quality of glycerine with a mixture of nitric and sulphuric acids, the proportions commonly adopted being 3 parts of nitric acid, 5 parts of sulphuric acid, and from 1 to 1.15 part of glycerine. The glycerine is added very slowly, and with constant stirring. The agitation of the mixture is now usually accomplished by compressed air.

Properties of Nitroglycerine. When made from the purest ingredients nitroglycerine is an oily-looking fluid, as clear and transparent as water. When freshly made it is whitish and opaque, but on standing it clears. As usually made it has a yellowish tint, but the best makers at the present day turn out a nearly water-white product. The specific gravity of nitroglycerine at ordinary temperatures is about 1.6, which increases when frozen to 1.735, showing that it contracts 10-121 of its volume on freezing. Nitroglycerine dissolves in alcohol, ether, methyl alcohol, benzine, etc., but is nearly insoluble in water (about 0.003 per cent.). Freshly made opaque nitroglycerine freezes at from—2.2°F. to—7.6°F., while the transparent or "cleared" product freezes at from 39.2°F. to 37.4°F. In a frozen state nitroglycerine is less sensitive to shock or concussion than when liquid, but on breaking frozen crystals a peculiar molecular change occurs, from which explosions result. It may be completely evaporated at a temperature of 158°F., and dynamite will lose 10 per cent. of its nitroglycerine if exposed for several days to a temperature of 104°F. It is claimed to very slowly volatilize at normal temperatures above its freezing point.[3] Its ignition temperature, or, more properly, firing point, is 356°F. Exposed to a temperature of 365°F. it boils with the evolution of vapors. At 381.2°F. it volatilizes slowly. At 392°F. it evaporates rapidly. At 422.6°F. it detonates violently. From this point its behavior changes, passing through temperatures at which it explodes with con-

[3] Dwight Brainerd, General Agent Hamilton Powder Co., Montreal.

stantly lessening violence until, at a dark cherry red heat, it merely assumes the spheroidal state and fails to explode. This is true for small quantities only. When gradually heated it is certain to explode at 356°F. If other nitrous compounds are present, due to faulty glycerine or faulty washing, nitroglycerine will explode at lower temperatures. These also start the decomposition of the nitroglycerine itself, and are thus productive of spontaneous explosions.

Nitroglycerine is rapidly decomposed by yellow ammonium sulphide, and other alkaline sulphides, with the separation of sulphur. It is slowly decomposed by an alcoholic solution of potassium hydrate, by ammonia, carbonate of soda (sal soda), and other alkaline carbonates, by hydrogen-sodium phosphate, hot water, ferrous chloride and sulphuric acid. All acids cause its decomposition, and traces of acids remaining in it from its manufacture lead to deterioration; hence the importance of an absolutely acid-free nitroglycerine. Any acidity may be detected by litmus-paper (turning blue litmus paper red). For its safe decomposition by inexperienced persons a strong solution in water of sodium carbonate (sal soda) is best. The decomposition is slow and unattended by danger. Gentle stirring with a wooden paddle will facilitate the reaction.

The action of the direct rays of sunlight is known to cause the decomposition of nitroglycerine, and may provoke an explosion. When decomposition sets in it usually, but not always, proceeds in a tranquil manner, disengaging nitrous fumes which color the nitroglycerine green, then developing nitrogen and carbon dioxide (carbonic acid) and crystals of oxalic acid. After some months the entire mass is converted into a greenish gelatinous body composed of oxalic acid, water and ammonia. But decomposition is not always so quietly accomplished, especially if the temperature is high, as when heated by the sun. It is not to be trusted. If treated to a temperature of 212° F. for a few hours it decomposes.

In small quantities nitroglycerine will burn quietly, but with large quantities the heat thus generated will bring the entire mass to the explosion temperature before it has burned away. The critical temperature for nitroglycerine lies between 113° F. and 122° F., and its sensitiveness is greatest just above the freezing point.

Pure nitroglycerine is not sensitive to friction or moderate percussion, except when pinched between metallic surfaces. A quantity of it has been thrown up by means of a rocket to a height of 1000 feet, from which it fell without being exploded by the impact. When impure, or in a state of decomposition, however, it is exceedingly sensitive and explodes violently on shock, even when unconfined. The best nitroglycerine when confined is liable to explosion by shock.

Nitroglycerine taken internally, except in minute medicinal doses, behaves as an active poison.

In its pure state nitroglycerine is but little used to-day for blasting. It is still employed to some extent for large blasts, but its chief use is for "shooting" oil and gas wells to open up the rock and increase the yield of oil or gas. The nitroglycerine is put into tin shells from three to five inches in diameter and from five to twenty feet in length. A strong detonating cap is placed in the cover of this shell, which is then lowered to the bottom of the well by means of a wire. A perforated iron or lead weight is then strung on the wire, and the torpedo is exploded by allowing the weight to run down the wire and strike the cap.

Blasting Powders made from Guncotton and Nitroglycerine. The use of guncotton for blasting in any form is not extensive. One of the best known preparations is tonite, now called cotton powder, made by the Tonite Powder Co. It consists of

Guncotton	52.5 parts
Barium nitrate	47.5 parts

These are thoroughly incorporated, and put up in cartridge form in paraffined paper. From its composition it would manifestly be an exceedingly safe explosive to handle, and its power should be very great, but the author possesses no reliable information as to its efficiency. Recent patents on cotton powder call for the addition to its composition of charcoal, or meta-di-nitrobenzol, either of which would apparently increase its strength, and perhaps reduce its insensitiveness. The original tonite is said to have required a special detonator, failing to explode with even the treble or quintuple strength caps sold for other high explosives.

Potentite resembles tonite, substituting nitre for the barium nitrate. Its composition is

Guncotton	66.2 parts
Potassium nitrate	33,8 "

Dynamite is the most largely used of any blasting material in the world. It was invented in 1866 by Alfred Nobel. The principle consisted in using an absorbent, commonly called a "dope," which would take up the nitroglycerine and hold it somewhat after the manner of a sponge. A suitable dope should possess a cellular structure, so that the nitroglycerine may be subdivided into minute globules, each globule held separately in its own cell, completely isolated from every other. In this condition its sensitiveness is greatly reduced, depending of course upon the amount of nitroglycerine absorbed. Dynamites may be classified according to the nature of the absorbent used. The following classification is given by Walke :

I. Dynamite with an inert base
(Kieselguhr, Magnesium Carbonate.)

II. Dynamite with an active base.
- A. Combustible base, (carbodynamite).
- B. Explosive base.
  - 1. Explosive mixture.
    - *a.* Mixture of the nitrate class.
    - *b.* Mixture of the chlorate class.
  - 2. Explosive compound.
    - *a.* Nitro-substitution compound.
    - *b.* Nitric derivative compound.

The original dynamite of Nobel consisted of nitroglycerine absorbed in kieselguhr, or diatomaceous earth. This material consists of the siliceous remains of micro scopic plants, called infusoria or diatoms. These contain microscopic cells and capillary tubes, within which, when the nitroglycerine is once absorbed, it is tenaciously held. The nitroglycerine is thus cushioned against the effects of sudden shocks, and will normally explode only under the powerful impulse of a detonator. The kieselguhr is cleansed and calcined with great care, and will then take up 75 per cent. of nitroglycerine. According as the percentage of ni roglycerine is reduced the dynamite becomes less sensitive, and at 40 per cent. it requires a powerful detonator to insure explosion. With 20 per cent. of nitroglycerine it cannot be exploded. Magnesium carbonate, though a valuable absorbent, will not hold the nitroglycerine as effectually as kieselguhr. It is used to some extent as a mixture in other dopes. Kieselguhr dynamite is the typical dynamite, but it is not made in America, since other less expensive dopes are available, which under proper conditions afford an almost equal degree of security.

Dynamite with a Combustible Base. The only well known dynamite of this class is carbodynamite, which consists of

Nitroglycerine	88.66 parts.
Carbon	9.85 "
Sodium carbonate	1.49 "

The carbon is an exceedingly porous variety of charcoal made by carbonizing cork. It does not disintegrate nor "leak" nitroglycerine, but its cost is prohibitive.

Dynamite with an Explosive Base: Nitrate mixture class. The earliest experiments of Nobel to produce what we now know as a dynamite consisted in making cartridges of black powder and pouring nitroglycerine into them. Similar attempts to combine the two explosives have often been made, since it was expected that the detonation of the contained nitroglycerine would also cause the detonation of the gunpowder, thereby increasing the power of the latter about four-fold. The most highly perfected explosive of this kind is the Judson R.R. P. powder, which consists of a special honey-combed gunpowder, which absorbs 5 per cent. of nitroglycerine and remains a free running powder.[4] It is particularly recommended for seam blasting. The common Judson powder, which also belongs to this class, contains

Nitroglycerine	5	parts.
Sodium nitrate	64	"
Sulphur	16	"
Cannel coal	15	"

Vulcanite resembles this, replacing the cannel coal by charcoal and increasing the amount of nitroglycerine. Its composition is

Nitroglycerine	30.0	parts.
Sodium nitrate	52.5	"
Sulphur	7.0	"
Charcoal	10.5	"

Powders of this character mark a radical departure from the original dynamite with an inert base. Attempts were made to find a less expensive but reliable inert dope,

[4] Prof. Charles E. Munroe.

and later the effort was made to use a nitrate mixture with a certain proportion of an inert substance to limit its sensitiveness. The advantage of so doing is problematical. Sufficient care in preparing the combustible material in the nitrate mixture is undoubtedly of more value than the admixture of any earthy ingredient. As examples of dynamites with nitrate mixture dopes containing mineral deterrents may be cited the following:

STONITE.

Nitroglycerine	68	parts.
Keiselguhr	20	"
Woodmeal	4	"
Potassium nitrate	8	"

ATLAS POWDER.

Nitroglycerine	75	parts.
Wood fibre	21	"
Sodium nitrate	2	"
Magnesium carbonate	2	"

GIANT POWDER NO. 2.

Nitroglycerine	40	parts.
Sodium nitrate	40	"
Sulphur	6	"
Resin (powdered)	8	"
Kieselguhr	8	"

There is no objection to be urged against the use of a small quantity of inert substance in the dope, but it is not necessary. The dynamites of commerce in America are probably about equally divided between those with and without such an admixture. As examples of standard dynamites which do not contain this ingredient the following are sufficiently representative:

RENDROCK.

Nitroglycerine	40	parts.
Potassium nitrate	40	"
Woodpulp	13	"
Pitch	7	"

CARBONITE.

Nitroglycerine	25.0	parts.
Woodmeal	40.5	"
Sodium nitrate	34.0	"
Sodium carbonate	0.5	"

DUALIN.

Nitroglycerine	40	parts.
Sawdust	30	"
Potassium nitrate	20	"

Chlorate Mixture Class. The same objection which applied to the chlorate mixture powders may be urged with equal force against dynamites containing potassium chlorate in the dope. Those which have given the best results are the following:

HORSLEY POWDER.

Nitroglycerine	72	parts.
Potassium chlorate	6	"
Nutgalls	1	"
Charcoal	1	"

VIGORITE.

Nitroglycerine	30	parts.
Potassium chlorate	49	"
Potassium nitrate	7	"
Woodpulp	9	"
Magnesium carbonate, moisture, etc	5	"

HERCULES POWDER.

Nitroglycerine	40.00	parts.
Potassium nitrate	31.00	"
Potassium chlorate	3.34	"
Magnesium carbonate	10.00	"
Sugar	15.66	"

In all the above dopes, where woodpulp or sawdust is employed it should consist of a porous wood, such as basswood or spruce. Woodpulps vary considerably in the amount of nitroglycerine they will absorb, ranging from about 60 per cent. to 85 per cent. Before introducing the nitroglycerine it should be thoroughly dried, on no account being allowed to retain more than 1 per cent. of moisture. Nothing is more certain to cause deterioration of dynamite, with "leaking" of the nitroglycerine, than moisture, and dynamite so deteriorated is exceedingly dangerous and should not be used.

Characteristics of Common Dynamites. The characteristics of the ordinary dynamites, which are those having dopes of the nitrate and chlorate mixture class, may be considered before giving an account of the more peculiar combinations of nitroglycerine with nitro-substitution and nitric derivative compounds. There are certain requirements which all dynamites should fulfil, and it is the duty of all persons using or handling them to see that they do not fall short of the proper standard. Good dynamite should not feel greasy. There should be no trace of free nitroglycerine inside the wrapper of the cartridge. In order to test this point, lay one of the suspected cartridges on a sheet of clean brown paper in a room at from 60° to 80° F. for a period of about 12 hours. If the cartridge has begun to "leak" nitroglycerine, this will be shown by an oily discoloration on the brown paper. Dynamite properly made should be proof against leakiness under normal conditions of temperature and moisture. To test its quality in this respect two separate determinations should be made. First, freeze and thaw samples of the dynamite three successive times, and test for leakiness as explained above. Second, expose samples to a temperature between 85° and 90° F. for six consecutive days and nights, and again test for leakiness. In neither case should any trace of free nitroglycerine be seen on the brown paper. If slowly heated dynamite explodes at 356° F., and if rapidly heated it explodes at 446° F. These temperatures apply only to kieselguhr dynamite. The American dynamites, containing woodpulp and nitrates, will explode at somewhat lower temperatures. Like nitroglycerine, it is most sensitive to shock or friction just above its freezing point. According to the character of dope used it freezes at from 42° to 46° F. It is nearly if not quite insensitive to shock when frozen, but not entirely so to friction. Cartridges broken while frozen are liable to explosion from molecular disturbance of the nitroglycerine crystals. Ramming frozen sticks into a hole is attended with the same danger. Explosion of frozen dynamite may be due to long crystals of nitroglycerine with films of unfrozen nitroglycerine, exploded by friction.[5] Frozen dynamite is not incapable of being detonated, especially if very powerful detonators be used. Any efflorescence, whitish film, or incrustation on dynamite cartridges indicates either that the dynamite itself contained an excess of moisture in the dope, or (what is most likely to be the

[5] Dwight Brainerd.

cause) that it has been subjected to excess of dampness in transportation or storage. In either case the incrustation is due to the dissolving out of the nitrate of soda or potash from the dynamite. This has consequently destroyed its homogeneity, and such dynamite is almost always leaky, or will soon become so. It is unreliable, may fail to explode in blasting, and will produce noxious fumes if it does explode. Its power as an explosive has been reduced also, so that it possesses the disadvantages of being dangerous to handle, unreliable as a blasting agent, and at best uneconomical. It should not be used, but should be destroyed.[6] Exposure to the rays of the sun, especially if transmitted through window glass, is liable to produce decomposition and explosion. A strong electric discharge, or a flash of lightning, will usually explode dynamite. Dynamite placed in water gradually parts with its nitroglycerine, its place in the cartridge being taken by the water. Attention is specially drawn to this fact because of the popular impression that dynamite is unaffected by water, an error that has probably arisen from the fact that it can be used in wet holes or under water. In wet situations it should be fired within a reasonable time after preparing the charge, and under no circumstances allowed to remain unexploded for a period of many hours; otherwise nitroglycerine will leak out and find its way into crevices, where it may cause accidents later on. The characteristics given above apply to all those explosives known popularly as dynamite,

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[6] See Chapter IV.

giant powder, dualin, atlas powder, hercules powder, rendrock, etc.

Dynamite with an Explosive Base of the Nitro-substitution class. This species of dynamite is little known in America. Its best representative is Castellanos powder, which contains a picrate, usually picrate of ammonia, in the dope. Its composition is

Nitroglycerine	40	parts.
Picrate	10	"
Sodium nitrate	25	"
Carbon	10	"
Sulphur	5	"
Some insoluble salt	10	"

Dynamite with an Explosive Base of the Nitric Derivative class. The representative of this class of explosives is what has been called blasting gelatine. It consists of soluble guncotton dissolved in nitroglycerine by the aid of heat, the result being a tough, jelly-like, translucent, elastic substance, varying in color from bright yellow to yellowish brown. It has a specific gravity of 1.6, does not absorb water, and when placed in it is affected only on the surface, and no further change occurs. Unconfined it burns, but does not explode. Heated slowly it explodes at 399° F., and heated rapidly it explodes at 464° F. At low temperatures it freezes into a hard solid of crystalline structure. The temperature at which it freezes is somewhat variable, but usually this occurs between 35° and 40° F. It is far more sensitive when frozen than when unfrozen, and can be readily detonated or exploded by the impact of bullets. It is peculiarly adapted to use in warm climates. It will not leak nitroglycerine, even after repeated freezing and thawing, nor after prolonged exposure to a temperature of 90° F. It is more powerful than ordinary dynamites, and requires a stronger detonator to develop its maximum intensity.

Gelatine dynamite is an explosive in which the blasting gelatine has been incorporated with a dope to modify its action. The best known gelatine dynamites are the following :

GELIGNITE.

65 per cent. of blasting gelatine containing................	Nitroglycerine	$96\frac{2}{13}$	per cent.
	Collodion cotton	$3\frac{11}{13}$	"
35 per cent. of absorbent, containing....................	Sodium nitrate	75	per cent.
	Sodium carbonate	1	"
	Woodpulp	24	"

FORCITE.

50 per cent. of blasting gelatine containing................	Nitroglycerine	98	per cent.
	Collodion cotton	2	"
50 per cent. of absorbents, containing..................	Sodium nitrate	76	"
	Sulphur	3	"
	Woodtar	20	"
	Woodpulp	1	"

For these explosives a test for stability is of importance. For this purpose repeated freezing and thawing, followed by the test for leakiness, as with ordinary dynamites, and prolonged exposure to a temperature of 90° F., again testing for leakiness, are requisite. Any tendency to leak under such circumstances is due to the presence of moisture in the ingredients, and the fault lies entirely with the manufacturer, and not with exposure to unsuitable conditions in transportation and storage. It possesses many advantages over common dynamites, and is rapidly supplanting them in most European countries. It is not, however, as safe a material, being liable to spontaneous explosion, and being entirely untrustworthy in cold weather. Until these disadvantages are overcome it is not a desirable explosive to put into the hands of inexperienced persons.

5. Explosives of the Sprengel Class.

Dr. Hermann Sprengel in 1873 called attention to a new class of explosives whose principle consisted in the admixture, immediately before use, of two ingredients, themselves inexplosive, but producing when mixed a substance capable of violent detonation. The mixing of the ingredients cannot usually with safety be done by unskilled persons, but in the hands of a careful manipulator they are of great value. This class of explosive is being extensively employed by the Russian government in Siberia, and where transportation may be attended with danger, or where large supplies may have to be kept for a prolonged period, the Sprengel explosives are peculiarly desirable. The most successful of these has been Rack-a-rock, manufactured by the Rendrock Powder Co. It consists of

Potassium chlorate...........................	79 parts.
Mono-nitrobenzene	21 "

The potassium chlorate is made up into cartridge form, being specially prepared so as to increase its absorptive quality. The liquid mono-nitrobenzene is put up in vessels containing the proper proportion to saturate the cartridge. The immersion is made about ten minutes before use. It is no more dangerous, perhaps less so, than common dynamites, though it would develop the untrustworthy character of all chlorate mixtures if kept. Its specific gravity is 1.7, and it requires a powerful detonator.

Liquid explosives of this class have been patented, and have met with some favor abroad, but the difficulties attendant upon the use of a liquid in blasting are so great that it can be employed to advantage only in very special cases. As an example of these may be given

HELLHOFFITE.

Meta-di-nitrobenzene	47 parts.
Nitric acid (sp. g. 1.50)	53 "

A very powerful detonator is required to explode it. Its intensity appears to be greater than nitroglycerine, and it is claimed to resist explosion by a shock or an open flame.

6. FULMINATES, AMIDES, ETC.

These are the most powerful and dangerous explosives in common use. They consist for the most part of metallic salts of fulminic and amic acids. The formula $H_2C_2N_2O_2$ has been assigned to fulminic acid, though it has never been isolated. The commonest fulminate, known as mercury fulminate, is formed by dissolving mercury in nitric acid, to which solution, when cool, is added 110 parts of alcohol. Water is then added, causing the gray fulminate to precipitate. This is carefully washed and air dried. The operation is attended with great danger. The color of the fulminate varies from white to dirty gray. Its specific gravity is 4.42; it has a sweetish taste and is highly poisonous. It is extremely sensitive to heat and shock of every kind. Its firing point when slowly heated is 305.6° F., and when heated rapidly 368.6° F. It is less sensitive, but not secure against explosion, when wet. The slightest friction will provoke its explosion. It may be destroyed safely by treating it with alkaline sulphides.[7]

Fulminates of other metals are capable of being made, such as fulminates of silver, gold, platinum, zinc and copper, but these are more violently explosive, and less stable, than mercury fulminate ; the only one which has come into any use being the silver compound, and this not in industrial operations.

The amides are still more perilous, and are of no economic importance. Iodoamide, or nitrogen iodide, is so unstable that it will explode on being touched with a feather, its destructive effect being very great. These latter compounds are of interest only to the chemist and experimentalist.

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[7] See Chapter II.

CHAPTER II

FUSE, CAPS AND METHODS OF FIRING.

The explosion of blasting powders is accomplished either by the direct application of a high temperature unaccompanied by a shock, as in the firing of gunpowder by a fuse, or by the application of a very powerful shock in which the high velocity of the explosive wave is of more consequence than the temperature, as in the explosion of dynamites by caps or detonators loaded with fulminating compounds. The detonators may be exploded electrically or by fuse.

Safety Fuses.

Safety Fuses, also commonly called Bickford Fuses, after William Bickford of Cornwall, who patented them in 1831, consist essentially of a powder thread spun around with jute yarn, and impregnated with compositions to make them waterproof. The core of powder being tightly compressed in a thin continuous thread within the fuse, the fire only travels along it slowly, the rate of burning of a good fuse being about 30 seconds per foot. In the Bickford process a number of jute threads pass through an orifice while they are slowly rotating, a fine current of meal gunpowder being fed into the jute tube thus formed The cord is kept stretched in a perpendicular position while being formed around its core of powder. This cord is then sent to another machine, which spins a second layer of jute yarn around it in the opposite direction. The fuse is next drawn through a bath of coal tar, to which a little wood-tar has been added. This coats externally and partly penetrates the cord. Subsequently it is drawn through fuller's earth, or china clay, and then cut into lengths. This makes the "single black fuse," which is moderately waterproof. The white fuses are treated with china clay made into a paste with glue size, and red fuses are coated with bolus powder. These are less waterproof than the black fuse. For wet bore-holes "double" and "tape" fuses are employed. The "double" fuses are made like ordinary black fuse, and then rewound with another layer of yarn and again coated with tar and clay. "Tape" fuses are wound with waterproof tape, overlapping. For blasting under water special gutta-percha covered fuse is manufactured. A great variety of fuses are made, differing in the character of the covering put around the original yarn containing the powder core.

Quick Burning and Detonating Fuses.

In order to accomplish simultaneous firing of a number of holes with fuse instead of by electricity quick-burning fuses are made by coating a wick with meal powder paste, having yarn loosely spun over it. In order to fire a number of shots at once the several fuses, all of equal length, are attached to a sheet iron connector, in one end of which is a disk of powder and a perforated wooden plug for the insertion of an ordinary safety fuse. The quick burning fuse burns at the rate of 500 feet per second.

A similar fuse made in Austria contains a quick-burning core consisting of four cotton threads filled with a paste of equal parts of ferrocyanide of lead and potassium chlorate mixed with alcohol. This however, is slower than the Bickford rapid fuse.

A practically instantaneous fuse is that invented by Col. Philip Hess, which is known as a detonating fuse. In this a cotton thread is saturated with a paste of mercury fulminate. The ends of the fuse are subjected in the connector to the action of a detonating cap. The rate of transmission of the explosion through this fuse is 16,400 feet per second.[1]

Fuse should be kept perfectly dry, preferably in canisters, and care should be taken to keep it out of contact with oils.

Detonators or Exploders.

For use with high explosives a detonating cap is essential in order to impart a sufficient initial impulse to develop the full strength of the powder. These differ from caps employed for sporting ammunition in that the heat engendered in exploding the fulminate is employed in the latter to ignite the powder, the quality of the fulminate used being very small, and it is fired in contact with the powder. In the case of detonators, however, the fulminate is enclosed in a copper capsule, out of contact with the explosive. The detonation of the fulminate pulverizes the end of the capsule, so that the temperature resulting from it is communicated to the explosive, but it

1 Guttmann, The Manufacture of Explosives, vol. II. p. 300.

is the violence of the shock that is relied upon to start the detonation of the high explosive. For this purpose considerably larger quantities of the fulminate of mercury are employed. The ordinary detonator, whether made for firing by fuse or electricity, contains usually

Mercury fulminate	75 parts
Potassium chlorate	25 "

Some manufacturers use potassium nitrate instead of the chlorate. Detonators are graded according to the amount of mercury fulminate in the composition, as follows:

Single strength	3 grains of mercury fulminate
Double "	6 " " "
Treble "	9 " " "
Quadruple strength	12 " " "

And so on. The stronger the detonator used the more powerful will be the detonation of the dynamite or other high explosive. The treble strength should be used in ordinary practice, and will prove to be more economical than the lower grades.

The fulminating composition is compressed in the end of the capsule and then covered with shellac, collodion, celluloid, or thin copper foil or paper, to prevent the composition from coming out. The end of the capsule above the composition is then left open to receive the fuse. In electric detonators, a piece of resistance wire, usually platinum, is compressed in the composition, the ends being attached to copper wires leading out through a hard plug of sulphur and ground glass which fills the capsule. These wires are wound with cotton insulation. The heating of the short piece of resistance wire to incandescence, due to the passage of the electric current, explodes the fulminate. This is the most reliable form of electric detonator, which, however, requires currents of great intensity, though of low tension, to generate which powerful electric machines are required to fire a large number of detonators. Another common form is the slot detonator A plug of melted sulphur and powdered glass is molded over a U-shaped piece of brass wire. A fine slot is then cut through the wire at the centre of the bend. The plug is then inserted into the capsule so that the two bent ends of the wire project into the priming mixture of antimony sulphide and potassium chlorate, which in this kind of cap is placed on top of the fulminating composition. The bridge detonator is similar to the slot form, except that the terminals are filed off flush with the inside face of the plug, along which a line is drawn from one terminal to the other with a soft black lead pencil, thus forming a path for the current with many points at which sparking takes place. This form of detonator is very sensitive, and great care must be taken in its manipulation and coupling up.

Firing.

In the use of fuse for exploding gunpowder it is only essential to see that the end of the fuse is well buried in the charge. This applies whether the powder is poured loose into a dry hole, or is made up in cartridge form. When made into cartridges the ends of the paper should be securely tied around the fuse, but not so tightly as to constrict it and interrupt the continuity of the powder core. The cartridges may be made by using a long strip of brown paper, folding one end around the end of a cylindrical wooden form, and then spirally winding the paper upon the form, with the edges well overlapping. Before removing the case thus made from the form it should be dipped into melted paraffine, giving it several coats. If the hole is very wet another wrapping in the reverse direction, with a coating of paraffine, will insure the dryness of the charge, and after loading and attaching the fuse it may be immersed up to the fuse in the molten paraffine, making sure that it is not appreciably hotter than the melting point of the paraffine, viz., 113°F. This will make a perfectly water tight cartridge, but of course cannot be rammed in a hole.

A detonator is employed only with high explosives. One end of the cartridge paper is opened up and a hole is made by firm pressure with a hard-wood instrument, with a rounded end, no larger in diameter than the cap to be inserted. The hole should be driven to no greater depth than is suitable for the cap, so that the end of the cap shall reach the bottom of the hole and leave at least $\frac{1}{8}$ of an inch of the end of the copper capsule projecting above the end of the cartridge. Otherwise the fuse coming in contact with the dynamite may ignite and explode it before detonation can occur, thus greatly reducing the power of the explosive, and producing deleterious fumes from the imperfect combustion of the powder. The ends of the paper of the cartridge are now drawn closely around the fuse, and tied as before. The cartridge thus prepared is called the "primer." The same method is pursued in placing the electric detonator, with the difference that it is not objectionable to bury the cap in the dynamite. This is recommended by G. G. Turner as insuring success. Under no circumstances, however, must this be done with caps fired by fuse. It is of the utmost importance, in order to realize the full force of the explosive, that the cap shall fit neatly and accurately in the hole made for it in the dynamite. An air-space, even of a small fraction of an inch below the cap, will serve as a cushion, masking the force of the detonation of the cap, and reducing the initial violence of the explosive wave imparted to the dynamite, upon which directly depends the violence of the explosion which it produces.

The end of the fuse which is to be inserted into the cap should be cut off square across, preferably with a fuse-cutter such as is supplied by all dealers in explosives, and then holding the fuse vertically with this end up, slip the cap lightly over it. Do not press it on to the fuse, nor turn it on the fuse end, as this may explode the cap by friction. Then crimp the walls of the cap about $\frac{1}{8}$ inch from its upper end upon the fuse by means of the crimper, which is combined with the fuse-cutter above mentioned. No other instrument should ever be used, and under no circumstances should the cap be bitten upon the fuse. To do so is to run a tremendous risk. Let any one who doubts this explode a cap held against a No. 18 iron plate, by fixing the cap in a hole bored in a block of wood and fixed against the iron. After seeing the hole which an ordinary detonator will make through such a piece of metal, he would be a fool indeed who would again bite so sensitive an explosive agent with his teeth.

The free end of the fuse should be kept up out of the water, and no two fuses should cross each other. A slit should be cut a half-inch long in the end to sufficiently expose the core for prompt lighting. It is not good practice to attach wicking or other material soaked in oil to the end of the fuse for igniting it, but dry paper may be twisted upon the end if desired. If properly slit, and turned sideways so as to expose the core without shattering out the powder, the fuse can be readily lighted with a candle flame.

In firing by battery the ends of the copper wires attached to the detonator are to be twisted tightly upon the ends of the heavily insulated "leading wires." The ends should be bent over, forming a hook, so that the detonator wire may by no chance become detached. The ends of the wires must be scraped bright, so as to insure ample contact between clean surfaces to carry the electric current. Where more than one hole is to be fired

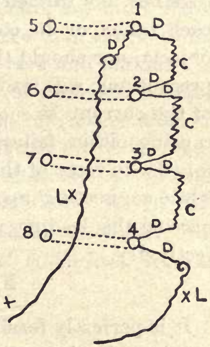

Fig. 1.

at the same time, connecting wire is employed to connect up the whole series of charges. The method of wiring is shown in the accompanying sketch (Fig. 1) which is assumed to represent a V-cut for the "bearing-in shots" in a tunnel breast. Here the 8 shot-holes indicated constitute the "unkeying," or "breaking-in" shots. Of these, Nos. 1, 2, 3 and 4, being shorter than Nos. 5, 6, 7 and 8, are fired first; hence these are connected for one volley. In the figure, L L are the leading wires, D D D etc., the detonator wires, and C C C the connecting wires. The connecting wire is of larger diameter than the detonator wires, but smaller than the leading wires, and less heavily insulated than the latter. Care must be observed not to allow any bare portions of one wire to touch another, nor to come into contact with the damp earth or rock. The leading wires should never be twisted together, nor carried to the working face in contact with each other, or in contact with pipes or other metallic objects, nor should they lie in water. Disregard of these precautions will lead to "short-circuiting," or grounding of the current as soon as the insulation is a little worn, causing either failure to explode the charges at all, or a mis-fire in some of the holes. The hands of the operator while connecting up the wires, and especially when connecting the leading wires to the battery, should be perfectly dry.

Firing Machines.

It is perfectly feasible to fire charges with battery cells and an induction coil, but such an appliance is not suited for work under the conditions of mining and quarrying operations. Various forms of frictional machines have been designed for blasting purposes, but they are sensitive to dampness, and require frequent testing. They are justly becoming obsolete. The standard blasting battery of to-day is a dynamo-electric machine, which is not affected by moderate dampness, and is always ready for use. In these there is an electro-magnet, between the poles of which rotates an armature, developing the current precisely as is done by an ordinary dynamo. The armature is driven by a rack and pinion, the current thus generated being rectified by a commutator. The armature is short-circuited until the rack in descending breaks the short circuit, and the current then passes into the firing circuit through the terminals or binding posts to which the leading wires are attached on the outside of the machine. Machines operated by a crank are more liable to accidents from a premature discharge than the so-called "pull-up" batteries, worked by the rack and pinion. A machine is rated at the full number of detonators which it will fire under favorable conditions. To insure freedom from mis-fires, it should never be worked up to its rated maximum capacity. With magneto-machines the leading wires, for distances up to 600 feet, should be No. 16 Birmingham gauge (0.065 inch), for distances of 800 feet, No. 14 (0.083 inch), and for distances of 1,000 feet, No. 13 (0.095 inch.)

CHAPTER III.

THEORY OF EXPLOSIVES AND FUMES.

An explosion is a chemical reaction which is completed in an exceedingly short period of time, with the evolution of a large quantity of gas at a very high temperature. If this reaction occurs in a body which is closely confined, the expansive effort of the highly heated gases produces disruptive effects. If the suddenness of the reaction is very great, disrupted action upon solid objects in contact with the body may be obtained even when it is unconfined, because the cohesion of these objects can be overcome more readily in an instant of time than the inertia of the surrounding air. This has given rise to the popular error that nitroglycerine and other high explosives act downwards. As a matter of fact they act with equal force in all directions. It is evident, therefore, that the violence of an explosion depends upon three things, viz., the time occupied in completing the reaction in the explosive body ; the temperature produced by the reaction, upon which directly depends the expansive force of the resultant gases; and the quantity of gases evolved by the reaction. A fourth consideration is whether the products of the reaction are the result of one set of chemical changes occurring simultaneously, or whether the set of new compounds react upon each other, producing a second set of com pounds.

Explosion and Detonation.

It must be observed also that there are two general classes of explosives : Those in which a process of oxidation occurs, and those in which there is simple dissociation of a compound without oxidation. Examples of the latter are nitrogen chloride (trichloramide) whose formula is NCl_3. It explodes violently according to the reaction

$$2NCl_3 = N_2 + 3Cl_2 .$$

The explosion of basic tin nitrate, $Sn_2N_2O_7$ may be of this character also, although it is possible that in its dissociation the tin is set free in the nascent state and then oxidized by the excess of oxygen present. Nitrogen iodide and nitrogen bromide and similar compounds give examples of simple dissociation without oxidation, attended with powerful explosive effects.

In all the common explosives, on the other hand, there is either simple oxidation or dissociation followed immediately by oxidation of carbon, the carbon and oxygen being contained in the explosive body. Hence such explosions may be considered as analogous to ordinary combustion, such as the burning of familiar combustible bodies, the difference being only in the extreme rapidity of the reaction.

Another distinction must now be noted between different classes of explosives. We have observed that explosives consist either of mechanical mixtures, such as gunpowder, or chemical compounds, such as nitroglycerine or guncotton. In the former class explosion occurs by the reaction of the particles of the different substances in the mixture upon each other, the explosion being propagated from one group of such particles to the next, and so on throughout the mass. An explosion so produced is necessarily relatively slow. A shock, unless of extreme violence so as to provoke sufficient friction, will not cause it to explode. The case is otherwise with explosive compounds. Here the elements composing the substance are combined into definite molecules of uniform composition, held together by a relatively feeble chemical attraction, *i.e.*, they are unstable chemical compounds. A shock will overcome the bonds which hold these elements together, upon which they are at once free to react upon each other, producing the gases at a high temperature that give an explosive effect. An explosive wave is thus generated, which is continued through the entire mass. If the shock be sufficiently violent, the energy of the initial wave will be reproduced uniformly throughout the body, perfect combustion is accomplished in an infinitely small space of time, and an effect of peculiar violence is obtained, which has been called "detonation." The same body may thus, according to circumstances, be exploded or detonated. Some substances, such as the fulminates and amides, always detonate, while others, like guncotton, nitroglycerine and the dynamites, may yield either phenomenon. The difference is apparently only one degree, but it is of great practical importance. Prof. Munroe, commenting on Lambert's experiments remarks,[1]

[1] Naval Institute, vol. x, p. 211.

"It is essential to observe that the explosive material does not detonate because it transmits the movement, but on the contrary because it arrests it, and because it transforms on the spot the mechanical energy into thermal energy, capable of suddenly raising the temperature of the substance up to the degree which will produce its decomposition."

Again, reviewing the researches of Berthelot, he says :[2] "Although neither acetylene, cyanogen nor nitric oxide can be detonated by simple heating, contact with flame, or the electric spark, yet it was found that the detonation of a small quantity of fulminate of mercury would instantly detonate them. The study of explosive matters presents analogous phenomena, for while with dynamite, for instance, simple inflammation is insufficient to provoke detonation, this is effected under the influence of special detonators, like fulminate of mercury, which gives rise to a very violent blow. This is due, as shown above, to the development of an explosive wave. Berthelot holds that the superiority of fulminating mercury as a detonator is not due solely to the rapidity of its decomposition, but is due in a great measure to the enormous pressure which it develops in detonating, a pressure greater than that of any known body, and which he estimates from his experiments to be equal to 40,000 kg. per sq. cm." (equivalent to 284.39 avoirdupois tons per square inch.) "The rate of propagation of the explosive wave increases with the density of the loading."[3]

[2] Naval Institute, vol. viii., p. 304.
[3] Berthelot, Compt. Rend. 100, 314 : 1885.

The rate of propagation of the explosive wave in dynamite upon detonation is from 7652 to 9030 feet per second. Anything in a powder which interferes with the transmission of the detonating impulse or wave will cause a diminution in strength through imperfect detonation. It requires 60 per cent. of nitroglycerine to make a powder of kieselguhr which can be depended upon to explode at all. As the nitroglycerine is increased the strength increases rapidly, through better transmission of the impulse. Even taking 75 per cent. as the utmost which the powder will safely hold, the detonation is not perfect under ordinary conditions, though it approaches it more nearly as the impulse is concentrated by stronger confinement.[4]

The effect of a rise of temperature is to bring all powders nearer the point at which they will explode or detonate. This heat effects a slight saving of work in explosion, so that all explosives are a little stronger in warm weather. Deliquescent ingredients in dynamite tend to elevate its temperature to a dangerous approximation to its ignition point, as follows: The air confined in the cartridge contains a slight quantity of moisture, which in uniting with the deliquescent salt causes a depression in temperature, which condenses fresh moisture from the surrounding air. This being taken up reduces the temperature still more, bringing a fresh supply, and so on. The process continues until arrested by an outside elevation of temperature, when the action is reversed. In losing moisture

[4] Lieut. W. R. Quinan, cited Naval Inst., vol. iv., p. 665.

the heat rendered latent is given out, which causes a fresh loss of moisture and further elevation of temperature, and so on, till a change in atmospheric conditions arrests the process. When absorbing moisture the dynamite is comparatively weak and insensitive to blows and compression; when losing moisture it is comparatively strong and very sensitive to both. The temperature being already elevated, a slight blow will raise it to the exploding point. The compression given by the tamping rod in compacting it in the bore-hole may be sufficient to cause a premature explosion.

While a nitrate mixture like gunpowder will not detonate, it has been frequently claimed that if combined with nitroglycerine a much greater power will be obtained. This has been maintained by Quinan and by Drinker, while others oppose it. The Judson R.R.P. powder is designed to accomplish this. The ratio of efficiency between gunpowder subjected to explosion and dynamite detonated is approximately as 1 : 2.26, and the ratio between dynamite and blasting gelatine, both detonated, is as 1 : 1.41.

An interesting practical illustration of the difference in the effect of the same explosive compound when detonated and when merely exploded is seen in the bursting of cast-iron shells loaded with guncotton. Where no detonation takes place the shell is broken into fragments of various sizes and of irregular shapes, but when detonation occurs the whole shell is reduced to very minute fragments, and, what is more remarkable, two-thirds of the total weight of the shell are found to be in approximately rounded particles like peas, and in the form of fine dust.[5]

Products of Combustion.

It has long been recognized that primary and secondary reactions occur in the explosion of gunpowder. Various theories, however, have been advanced to account for the phenomena presented. Perhaps the best summary of the results is that of Dr. Debus, who says: "The combustion of gunpowder consists of two distinct stages: a process of oxidation, occupying only a very small fraction of a second, and causing the explosion, during which potassium carbonate and sulphate, carbonic acid, some carbonic oxide and nitrogen are produced, and a process of reduction succeeding the process of oxidation, and requiring a comparatively long time for its completion. As the oxygen of the saltpetre is not sufficient to oxidize all the carbon to carbonic acid, and all the sulphur and sulphuric acid, a portion of the carbon and a portion of the sulphur are left free at the end of the process of oxidation. The carbon so left free reduces, during the second stage of the combustion, potassic sulphate, and the free sulphur decomposes potassic carbonate. Hydrogen and marsh gas, which are formed by the action of the heat upon the charcoal, likewise reduce potassic sulphate, and some hydrogen combines with sulphur forming sulphuretted hydrogen." The principal reactions taking place he represents by the following equations:

[5] Prof. Munroe, Nav. Inst. vol. xxii., p. 628.

First stage—

$$16 KNO_3 + 13C + 5S = 3K_2CO_3 + 5K_2SO_4 + 9CO_2 + CO + 8N_2$$

Second stage—

$$4K_2CO_3 + 7S = K_2SO_4 + 3K_2S_2 + 4CO_2$$

and

$$4K_2SO_4 + 7C = 2K_2CO_3 + 2K_2S_2 + 5CO_2$$

The possibility of dissociation is expressed by

$$K_2CO_3 + K_2S_2 + O_7 = 2K_2SO_4 + CO_2$$

The combustion of guncotton and of nitroglycerine proceeds along far simpler lines, from the nature of the substances involved. The reaction with guncotton is approximately:

$$2(C_6H_7O_2)O_3(NO_2)_3 = 9CO + 3CO_2 + 7H_2O + 3N_2$$

That for nitroglycerine is written

$$2C_3H_5O_3(NO_2)_3 = 6CO_2 + 5H_2O + 6N + O$$

The detonation of mercury fulminate gives

$$HgC_2N_2O_2 = Hg + 2CO + N_2$$

The fumes resulting from the explosion or detonation of ordinary blasting agents then contain as gaseous products carbonic acid, carbon monoxide, nitrogen and vapor of water, with some free oxygen in the case of nitroglycerine. There is no doubt, however, that when nitroglycerine or dynamites are not properly detonated considerable quantities of carbon monoxide are evolved. This goes far toward explaining its weaker explosive energy under such circumstances, the heat of formation being less, which proportionately reduces the expansive effect of the gases.

Physiological Effect of the Fumes.

The deleterious gases resulting from the explosion of common powders are carbonic acid (CO_2), carbon monoxide (CO) and nitrogen. The latter is evolved in comparatively small quantities, but its effect is the same as that of carbonic acid, simple asphyxiation. A patient overcome by carbonic acid and nitrogen, if rescued in time, will speedily be resucitated by an ample supply of pure air. The case is otherwise with carbon monoxide. This is a poison. If carbon monoxide, or air containing it, be inspired, it gradually displaces the oxygen, volume for volume, out of the red corpuscles, and death soon occurs. A very small quantity in the air ($\frac{1}{400}$ to $\frac{1}{1000}$) suffices in a relatively short time to form a quantity of carbonic-oxide-haemoglobin. In very partial poisoning with carbon monoxide the blood gradually gets rid of it through the respiratory organs. It does not appear that any part is further oxidized into CO_2 in the organism. Carbonic-oxide-haemoglobin, being a stable compound, circulates in the blood vessels, but it neither gives up oxygen to the tissues nor takes up oxygen in the lungs, hence its very poisonous properties. The real cause of death in animals poisoned with it is that the internal respiration is arrested. Its effects are first stimulation, and afterwards paralysis of the nervous system, as shown by the symptoms induced, *e.g.*, violent headache, great restlessness, excitement, increased activity of the heart and respiration, salivation, tremors and spasms ; later, unconsciousness, weakness and paralysis occur, labored respiration, diminished heartbeat, and, lastly, complete loss of sensibility, cessation of respiration and heartbeat, and death. At first the temperature rises several tenths of a degree, but it soon falls one degree or more. The pulse is also increased at first, but afterwards becomes very feeble and frequent. Where the quantity of carbon monoxide is large (as is the case after a blast in mines where the combustion of the explosive has from any cause been imperfect), there is temporary, but pronounced, paralysis of the limbs, followed by violent spasms.[6]

Dr. Thomas Darlington, who treated 1,300 cases of asphyxia, or partial asphyxia, and poisoning, from the products of the explosion of dynamite during the construction of the new Croton Aqueduct, New York, contributed an interesting paper on this subject to the Medical Record (38, 661-662 ; 1890). He says :

"Two classes of cases were observed : First, where a considerable quantity of the products was inhaled at one time—acute cases ; second, where the men constantly breathed a small amount—chronic cases. In some cases where the amount of dynamite used was not large, or where, after the explosion, a considerable quantity of fresh air has been mixed with the products of combustion, or where the workman has after a few breaths become giddy and is pulled away by others and sent to the surface, the effects produced are a trembling sensation, flushing of the face, succeeded sometimes by pallor, frequently nausea, sometimes vomiting, with throbbing through the temples

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6 Human Physiology. Dr. L. Landois, vol. i., p. 28, 1891.

and fulness in the head as if it would burst, followed by an intense headache characteristic of poisoning by nitrites, frequently lasting 48 hours. The heart's action is increased and the pulse full and round, though somewhat compressible. Where, however, a man goes into the tunnel immediately after the explosion, and is brought in contact with a large percentage of the poisonous materials, the effects are giddiness immediately followed by unconsciousness, and the patient presents the usual appearance of asphyxia. Sometimes in these cases the pulse is full and bounding, though very compressible ; but in most cases it is alarmingly weak. Generally there is great pallor. The comatose condition soon passes away, and is succeeded by drowsiness, languor, cold perspiration, intermittent pulse, and generally nausea and vomiting. Sometimes the breathing is spasmodic, and frequently there is hiccough, and after a time a severe headache. Nearly all of these cases no matter how serious they seem at the time, recover, though a substitute during my absence was on one occasion so unfortunate as to lose two cases. Death in these cases occurred several hours after the patients were removed from the tunnel, and was due to paralysis of respiration

"In the chronic cases there are four prominent symptoms, headache, cough, indigestion and disturbances of the nervous system. The cough is similar in character to the cough of pertussis, or of malaria. In nearly all of the cases there was a continuing headache. Next in prominence come disturbances of the nervous system, such as trembling, irritability, neuralgia, etc. Nearly if not all the symptoms were attributable to this cause. Even the cough, in all probability, was due to the effect produced on the pneumogastric nerve. As soon as a man with these chronic symptoms was taken from the tunnel and placed at work on top, he steadily improved, and would finally recover entirely. Those who had previously suffered from dyspepsia or neuralgia were made much worse by the dynamite smoke."

Dr. Darlington attributes much of the trouble experienced to the volatilization of nitroglycerine, which failed to explode. "The similarity of symptoms from inhalation of the products of the explosion of dynamite, and of those produced by the nitroglycerine itself, is so well marked that even miners themselves have noticed it. Frequently, when dynamite is frozen, a miner will place a cartridge in his boot to thaw it out, and the absorption of nitroglycerine through the skin will produce precisely the same symptoms as in the mild acute cases of the inhalation of the products before described. Again, I know an instance where a miner used his knife to cut a cartridge, and afterward cut and ate an apple with the same knife. In this case the symptoms were the same as those produced by powder smoke, only more severe. The headache persisted 3 weeks." He states that he proved the existence of free nitroglycerine in the air after explosions of dynamite by waving a glass plate in the fumes and condensing it thereon, subsequent tests proving it to be this substance. He remarks rather pertinently, "The use of a large cap will explode a greater percentage of the glonoine[7] than a small one, and this, to a certain extent, obviates the trouble. In certain cases, however, a cartridge does not explode, but burns like a candle, with considerable sputtering. In such an instance the amount of nitroglycerine volatilized is much greater than if exploded, and consequently the effects far more deleterious. I have witnessed a whole shift 'knocked out' from this cause."

Concerning the effects of nitroglycerine Dr. T. Lauder Brunton says,[8] "Its action is much like that of nitrite of amyl and other nitrites. It causes depression, with very rapid pulse and respiration, paralysis of reflex action and voluntary motion, loss of sensation and death by stoppage of the respiration. It agrees with nitrites in acting as a poison to muscle. The spinal cord appears to be paralyzed before the cerebral ganglia. It diminishes the oxidizing power of the blood and communicates to it a chocolate color like nitrites, and like them it also lessens the blood pressure. In some persons it produces headache, even in exceedingly minute doses. The reasons why nitroglycerine acts more powerfully than nitrites probably are that the whole of it is absorbed without decomposition, and the nitrous acid, being set free in the blood in a nascent condition, is more active than it would otherwise be."

It is evident that a mistake might easily be made in diagnosis between a case of poisoning by carbon monoxide

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[7] Glonoine is the medical term for nitroglycerine.

[8] "Pharmacology, Therapeutics and Materia Medica," 1885, p. 712.

(CO) and nitroglycerine, by depending upon superficial symptoms only, and Dr. Darlington has probably ascribed undue importance to the possibility of inhalation of free nitroglycerine in the fumes. Many of his acute cases were doubtless the results of carbonic oxide poisoning, the existence of which in the products of combustion of dynamite, especially when imperfect, he seems to have overlooked.

The line of treatment pursued by Dr. Darlington, the value of which is proven by his eminently successful results, is as follows: The usual procedure in cases of asphyxia. In addition to this, the use of cold applications to the head, and of atropine, ergotine or other vaso-motor stimulants, administered sub-cutaneously. Acting on the assumption that a nitrite is formed in the blood from the decomposition of nitroglycerine, he also treats his cases with inhalation of ammonia, and also gives the carbonate and aromatic spirits of ammonia internally. He recommends that workmen carry with them small vials of aromatic spirits of ammonia for immediate use in cases of necessity.

CHAPTER IV.

TRANSPORTATION, STORAGE AND HANDLING.

Transportation.

In the transportation of explosives by ordinary road vehicles the points to observe are: First, the vehicle should be inspected to make sure that it is in good condition, and not liable to breakage, and that it contains no projecting metal parts inside the bed. Second, that the cases containing the explosive are securely packed to prevent movement against or upon each other, or upon the sides and bottom of the bed. A small quantity of clean straw on the bottom of the bed and between the cases is a valuable precaution, especially when the explosives are to be hauled over rough roads. After unloading, the straw must be gathered together and burned at a safe distance from the explosives. Third, the cases must be covered in damp weather with a waterproof canvas or tarpaulin. In warm weather a white canvas cover over the vehicle is important to prevent undue heating from the sun. Fourth, the vehicle should always carry conspicuously displayed a signal flag to give warning of danger. Fifth, where possible, always avoid passing through a town, or the more densely populated portions of a town or settlement. Sixth, where necessary to pass through a town, do so quickly, without making any stoppages for any purpose. These or similar precautions are made obligatory by law in most counties.

For transportation of small lots of explosives around mines and quarries, they may be sent in tramcars, or lowered in skips, buckets or cages. Warning should always be given of the approach of such a cargo, and when feasible this work should be done between "shifts" so as to expose as few men as possible to danger. Only experienced and trusty men should be detailed for service of this kind. The carrying of a case on the shoulder is often the safest mode of conveyance of a small quantity. Under no circumstances should explosives be carried up or down ladders in a mine, except in very small quantities to working places for immediate use in the charging of bore-holes.

The regulations governing transportation by railroads vary with the roads themselves, more or less limited by legislation. The Ontario regulation contained in R.S.O. c. 207, s. 41, ss. 12 and 13, is as follows :

(12) No person shall be entitled to carry, or to require the company to carry upon their railway, aqua fortis, oil of vitriol, gunpowder lucifer matches, or any other goods which in the judgment of the company are of a dangerous nature ; and if any person sends by the railway such goods without, at the time of so sending the said goods, distinctly marking their nature on the outside of the package containing the same, and otherwise giving notice in writing to the bookkeeper or other servant of the company with whom the same are left, he shall forfeit to the company the sum of $20 for every offence.

(13) The company may refuse to take any package or parcel which they suspect to contain goods of a dangerous nature, or may require the same to be opened to ascertain the fact.

The Dominion Regulation, 51 V. c. 29, ss. 253 and 254, is as follows :

(253) No passenger shall carry, or require the company to carry upon its railway, aqua fortis, or oil of vitriol, gunpowder, nitroglycerine, or any other goods which, in the judgment of the company, are of a dangerous nature; and every person who sends by the railway any such goods without at the time of so sending the same, distinctly marking their nature on the outside of the package containing the same, and otherwise giving notice in writing to the station master or other servant of the company with whom the same are left, or who carries or takes upon any railway train such material as is mentioned above, for the purpose of having the same carried by the said railway train, shall forfeit to the company the sum of five hundred dollars for every such offence.

(254) The company may refuse to take any package or parcel which it suspects to contain goods of a dangerous nature, or may require the same to be opened to ascertain the fact ; and the company shall not carry any such goods of a dangerous nature, except in cars specially designated for that purpose, on each side of each of which shall plainly appear in large letters the words, "dangerous explosives," and for each neglect to comply with the provisions of this section the company shall incur a penalty of five hundred dollars.

The British law on this subject is very elaborate and explicit, as it is concerning the whole matter of explosives. The Secretary of State is given the widest authority in the making of regulations governing the transportation of explosives, and every harbor authority is empowered to make by-laws, with the sanction of the Board of Trade, regulating the conveyance, loading and unloading of gunpowder and other explosive substances. The orders of the Secretary of State prohibit the carriage of more than 5 lb. of any explosive in conveyances also used for passengers, and the carriage of fulminates, ammunition and fireworks in such conveyances is forbidden. Fulminates, ammunition and fireworks may not be carried in the same conveyance with other explosives unless a suitable distance for safety is maintained between them. Minute directions are given as to the packing of the cases in conveyances; separation from dangerous substances and sources of fire and heat; avoidance of centers of congested population; reliability and behavior of men in charge of the explosives; unloading, etc.[1]

"The quantity of explosive to be conveyed in any one carriage or boat shall not exceed 2,000 lb., unless the carriage be so enclosed on all sides with wood and metal, or the boat have a close deck so closed as to effectually protect the explosive against accident by fire from without, in which case the amount of explosive conveyed shall not exceed the following:

In any one carriage on a private railway, whether worked by steam or otherwise	10,000 lb.
In any other carriage	4,000 lb.
In any one boat	50,000 lb.

"When two or more carriages or boats conveying explosive exceeding in the aggregate the amount allowed by the preceding regulation to be conveyed in one such carriage

[1] Guide Book to the Explosives Act, 1875, 10th ed., pp. 172–180, and 325–330.

or boat are traveling together, a space of at least 50 yards shall be kept between each such carriage or boat, and every other such carriage or boat, unless circumstances render it impracticable, or unless, in the case of a train on a private railway, three or more vans not containing inflammable or explosive goods intervene between such carriage and every other such carriage."[2]

It will be found that governmental regulations touching such matters are usually more elastic than the self-imposed safeguards of the common carriers of widest experience. As an example of such voluntary regulations by a railroad company may be cited those which went into force on September 25, 1899, on the Pennsylvania railroad, a line which handles perhaps a larger quantity of explosive materials than any other in the world, and which has consequently had the most extensive experience. In order to show the degree of care which this corporation finds it advisable to take as part of its business policy, the order is quoted nearly in full.

1. Explosives will be received for transportation over the above lines (P.R.R., P.W. & B. R.R., N.C.S. Ry., and W.J.& S.R.R.) branches, and immediate connections under their control, only under the following regulations.

2. The safe transportation of explosives is believed to be largely influenced by the manner in which the explosives are packed for shipment. Furthermore, information in regard to the kind of explosive that is being transported is essential, in order that the railroad employes may not ignorantly do anything to incur danger.

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[2]Guide Book to the Explosives Act, 10th ed., p. 329.

3. *Classification.* For transportation purposes all explosives will be divided into the following groups: Common Black Powder, High Explosives, Smokeless Powders, Fulminates, Ammunition and Fireworks.

4. *Common Black Powder.* When these explosives are packed in packages containing less than 20 lb. each, these packages must be enclosed in a wooden box in such a way that the filling hole is up, and the boxes when filled must not weigh over 100 pounds. Each box must have stenciled on top: "Common Black Powder." The prismatic powders must be packed in tight tin boxes, which must be enclosed in a wooden box. The whole package must not weigh over one hundred pounds, and must be stenciled as above. When twenty pounds or over of sporting, rifle or blasting powder are contained in one package, this package is preferably a wooden keg or cask. If iron kegs or casks are used, it is desired that they be enclosed in a wooden jacket, but naked iron or steel kegs or casks will be received. These naked kegs or casks must be so well made, and the filling hole so well secured, that when filled with the same weight of sand as they are designed to carry of powder, and dropped in any manner a distance of four feet on a rail, they will not be ruptured and none of the sand will escape. These explosives will not be received in packages containing over one hundred pounds each, except for export, when larger packages will be received. Each package must be stenciled as above.

High Explosives. 5. Under high explosives are embraced all explosives more powerful than ordinary black powder, excepting smokeless powders and fulminates. These include those known under the various trade names of Acme, Ætna, Atlas, Climax, Commercial, Dittmar, Dynamite, Forcite, Fumeless, Giant, Hecla, Hercules, Joveite, Big Chief, Judson, Samson, Rend-Rock, Rack-a-Rock, etc., etc. The following regulations will apply to explosives of this group:

6. No explosive of this group will be received for shipment in the liquid or bulk form. Explosives like Rack-a-Rock, one constituent of which is liquid, will be received provided the liquid is not itself explosive, and provided the liquid is not packed in the same boxes with the other constituent. High explosives must be made up into cartridges, and the cartridges must be so arranged in the boxes that when the boxes are loaded top-side up all cartridges will lie on their sides, and never on their ends. Each package must be plainly stenciled, "High Explosive—Dangerous," on top and one side or ends. Explosives which consist of a liquid combined or mixed with an absorbent material must have the ingredients uniformly mixed and the liquid constituent thoroughly absorbed. The amount of the liquid constituent must be such that the temperature of the hottest summer day will not occasion leakage. The shells or cases consisting of paper or other material used in making the cartridges must be of such material, or be so treated, that the liquid constituent of the explosive will under no circumstances be absorbed by the case or shell.

Sections 7 to 10 refer to smokeless powders, which, being employed solely for military and sporting purposes, are not discussed in this Hand-book.

Fulminates. 11. Under fulminates for the present is included only fulminate of mercury in bulk form—that is, not made up into percussion caps, detonators, blasting caps or exploders. Fulminate of mercury in bulk must contain when packed not less than 25% of water, and must in this wet condition be placed in a twelve-ounce duck bag and securely tied. This duck bag must then be placed in a rubber bag, which rubber bag must then be filled with water and securely tied. The rubber bag and contents must then be placed in a tight cask, the empty spaces around the bag filled with sawdust, the cask closed and filled with water, then bunged and sealed. Each cask must be stenciled, 'Fulminate.' "

12. Under ammunition are embraced cartridges to be used in sporting or fowling pieces, etc., etc. . . . Also under ammunition are embraced *detonators, blasting caps, percussion caps, fulminators, exploders,* track caps, fog signals, and other articles of like nature. The following regulations apply to ammunition :

13. Cartridges or ammunition must be packed in pasteboard or other boxes, and these pasteboard or other boxes must be again packed in strong wooden boxes, not too large or heavy to be readily handled by one person. Each package or case of ammunition must be plainly stenciled "Ammunition—Handle Carefully." . . .

Sections 14 and 15 apply to fireworks.

Loading Explosives Together. 16. Black powder, high explosives and smokeless powder of all kinds may be loaded together in the same car. Fulminate, ammunition and fireworks must never be loaded with each other, nor in the same car with common black powder, high explosives or smokeless powder. . . .

Shipping Days. 17. Common black powder, high explosives, smokeless powders and fulminates, in car-load lots, will be received (when laws or ordinances permit) on any day except Saturday, and in less than car loads on Mondays and Thursdays of each week. Ammunition and fireworks will be received at any time, and may be loaded with other freight, except as provided in section 16, but should if possible be loaded so as to avoid transfer stations.

Then follow regulations as to shippers' certificates, and certificates of inspection of the car containing explosives, etc.

Selection and Preparation of Cars. 23. Only box cars which have been specially selected and specially inspected will be used in the transportation of the first four groups of explosives, and they must be in first-class condition in every respect, both inside and outside. The following points must be carefully looked after: The car must in no case have loose boards or cracks in the roof or sides, and the doors must shut so closely that no sparks can get in at the joints. When these explosives are loaded in car loads the doors must be stripped, except when the cars are equipped with Wagner doors, which must not be stripped. The journal boxes and trucks must be examined, and so cared for as to reduce to a minimum the probability of hot-boxes or other failure, requiring the car to be set off before reaching its destination. The car must be carefully swept before it is loaded, and a careful inspection made of the inside. Holes in the floor or lining must be repaired, and special care taken to see that there are no projecting nails or bolts, or pieces of metal which may work loose and produce holes in packages of explosives during transit. Short pieces of hard wood, two-inch plank, must be spiked to the floor over the king bolts to prevent the possibility of their wearing through the floor and into the packages of explosives.

24. Agents and car inspectors at junction points must refuse to receive from connecting lines cars loaded with these explosives unless the requirements of Section 23 have been complied with.

Handling of Explosives. 25. In handling packages of explosives at stations and in cars the greatest care must be taken to prevent their falling or getting shocks in any way, and they must not be thrown or dropped, but must as far as practicable be passed from hand to hand, or carried by one or more persons, and must not be rolled on the platform or car floor, unless they are so heavy that this cannot be avoided. The agent must choose careful men to handle explosives, must see that the platform and feet of the men are as free as possible from grit, and must take all possible precautions against fire. No unauthorized person must have access to the explosives at any time while they are on the property of the Company. Should any packages of high explosives when offered for shipment show outward signs of any oily stain or other indication that absorption of the liquid part of the explosive in the absorbent material is not perfect, or that the amount of the liquid part is greater than the absorbent can carry, THE PACKAGES MUST BE REFUSED IN EVERY INSTANCE AND MUST NOT BE ALLOWED TO REMAIN ON THE PROPERTY OF THE COMPANY.

26. All the articles enumerated in Section 12, under the heading Ammunition, also fireworks and friction matches, or other articles of like nature, must under no circumstances be loaded in the same car with the other kinds of explosives provided for in this circular; nor when unloaded be put near those explosives in the freight station.

Loading in Car. When explosives are packed in boxes, the boxes must be so loaded in the cars that they will lie flat, top-side uppermost. They must never be loaded on their sides or ends. When explosives are packed in round kegs containing from 20 to 100 lb., they must be loaded on their sides in rows across the car. Larger casks, barrels or drums may be loaded on their sides or ends as will best suit the conditions. Whatever the kind or form of packages, it is essential that after they are loaded THEY SHALL BE SO STAYED THAT THEY CANNOT CHANGE POSITION UNDER THE ORDINARY SHOCKS OF TRANSPORTATION. Especially must care be taken that they cannot fall to the floor or have anything fall on them during transit.

Section 28 gives instructions as to the marking of cars to indicate their dangerous contents, and Section 29 allows safety fuse, *if properly boxed*, to be loaded with other explosives.

Handling Car Containing Explosives. 30. Every person handling explosives in car-load lots or less must exercise the greatest care to prevent accidents. *A car containing explosives must be hauled as near the middle of a train as possible, and must not be placed next to a car loaded with oil or other inflammable material.* The locomotive must remain attached to the car or to the draft containing a car of explosives in handling it to or from a siding, if possible. When this can not be done, a rope or pole must be used, but *a flying switch must not be made with a car containing explosives.* Other cars must not be allowed to strike a car loaded with explosives, and such a car must be so placed in a yard or at a station that it will be subject to as little handling as possible, and that it will be exposed to as little danger from fire as possible. At every point at which a train stops the trainmen in charge must make a special examination of a car containing explosives, or other dangerous or inflammable articles, and must carefully examine the journal boxes with a view to locating or preventing hot boxes on these or adjacent cars. If it should be necessary to cut off, short of its destination, any car containing explosives, the conductor must advise the agent at the station where the car is cut off, and must also advise his superintendent from the first telegraph office. The agent at the point at which the car is cut off must use every possible precaution to prevent accident while the car is under his control.

In Case of a Wreck. 31. In case of a wreck involving a car containing explosives, the first and most important precaution is to prevent fire. Although most of the group "high explosives" will burn in small amounts quietly, and without causing a disastrous explosion, yet it must be remembered that it is the characteristic of most explosives to burn, and consequently everything possible must be done to keep fire away.[3] Before beginning to clear a wreck in which a car containing explosives is involved, all unbroken packages should if possible be removed to a place of safety, and as much of the broken packages as possible gathered up and likewise removed. Furthermore it should be borne in mind that "high explosives" are readily fired by a blow, and all explosives, except when they are wet, by the spark produced when two pieces of metal, or a piece of metal and a stone, come violently together. In clearing a wreck, therefore, care must be taken not to strike fire with the tools, and in using the crane or locomotive to tear the wreckage in pieces the possibility of producing sparks must be considered. With such explosives as "common black powder," "smokeless powders," and "fulminates," thorough wetting with water practically removes all danger of explosion by fire, spark, or blow;[4] but with the "high explosives" wetting does not make them safe from blows. With all explosives, mixing with damp earth renders them safer either from fire, spark or blow. In case "fulminate" has been scattered by a wreck, the ground involved must, after the wreck has been cleared, be saturated with oil. If this is not done, when the ground and fulminate get dry small explosions will constantly occur whenever the mixed material is trodden on or struck with any blow.

STORAGE.

Local conditions have much to do with the type of structure to be built for an explosives magazine. In

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[3] The regulations should have called attention to the fact that most explosives in bulk, after burning a short time, become heated thereby to their exploding temperature, and then explode with violence.

[4] Fulminates are not insensible to friction when wet.

general, it may be said, the lighter the construction the better. By the law of Austria all magazines must be built of such materials, and in such a manner, that in the event of an explosion the building will be completely disintegrated, and no pieces will be thrown to a distance. Thus the radius of danger is reduced to a minimum. The only points in favor of more solid construction are safety from fire and from burglars. The latter danger has been considered important in Great Britain, so that very substantial structures are there required. In America this precaution is of little moment, so that, in open country, where a sufficient zone can be obtained free from inflammable materials, the light construction is preferable.

Storage in caves, tunnels, earth- or stone-covered vaults and in log structures should under no circumstances be tolerated. The chief objection in all these cases is that the structure will hold dampness, and any dampness in a magazine containing any explosive into which nitrates enter as an essential or accessory ingredient is certain to affect its quality and render it more or less dangerous in subsequent use. This applies to gun-powder (common black powder) and to practically all dynamites, especially those made in America. It does not apply to kieselguhr dynamite of foreign manufacture.

A suitable building is one made of common weatherboarding on a framework of 2 by 4 inch stuff, with a tight flooring of tongued and grooved boards, blind nailed, and with walls and ceiling sealed with the same material. The roof should be of tarred paper. Where danger of fire is apprehended the lightest steel shingles may be used on the roof and outer walls. The door should be heavy, and should in all cases open outwards. Openings for ventilation should be provided around the bottom, protected by wire screens or otherwise against the entrance of vermin, and so constructed that water cannot enter. A hooded ventilating pipe should extend from the ceiling through the roof. In regions where danger of explosion from rifle balls is to be apprehended, safety may be insured by constructing inside the magazine a wainscoting, with a space of 6 inches between it and the wall, made sufficiently tight to hold fine dry sand, with which the interspace should be closely filled. If this is made as high as the top of the pile of cases holding the explosives, and the sand is well compacted and confined by boards covering the sand-space, no rifle now manufactured will be able to send a ball through this sand, even if fired as close as 25 feet from the magazine. This has been carefully tested by the author, using all grades of sporting rifles, and finally the Lee-Metford with its nickel-steel shell. In the latter case the maximum penetration, out of a large number of shots fired into sand confined in wooden receptacles, at a range of 24 feet 7½ inches measured from the muzzle of the rifle to the outside of the box, was 5 inches. In all cases the rear of the nickel-steel shell was found to be intact, but the point had been completely demolished, and the lead filling of the shell, on account of its greater momentum, had "spilled forward," and had been turned back by the resistance of the sand like the head of a mushroom, with the empty shell constituting the stem. The average penetration of lead bullets from ordinary sporting rifles was a little over 3½ inches at a range of 25 feet.

As a type of a suitable brick or stone structure the following specifications furnished by the Acadia Powder Co., of Halifax, N.S., are submitted :

General specifications. Brick magazine, (1,000 to 1,600 kegs of black powder or 15 to 20 tons of dynamite.)

Foundations of good rubble masonry, 24″ wide ; outside measurement, 16′ 2″ x 20′ 2″ ; height, 6″ above natural surface of ground ; depth according to location, average 4′.

Brickwork, 16′ x 20′ outside. Side walls, 16″ (2 bricks) wide up to string course for joists to rest on. Said course to be a plank 2¼″ x 8″, flush with inside brick work, at such height above foundations that bottom of joists may come 6″ above highest average snowfall. Where there is no snowfall nor danger of inundation, joists may rest directly on foundations. End walls, 1½ bricks wide. Above string course, building to be 14′ x 18′ inside ; 1st course, 12″ (1½ bricks wide) ; 2nd course, 10″ (1¼ bricks) all around building except buttresses, 12″ wide and 16″ (2 bricks) face, carried up at each corner and in centre of rear and end walls ; 3rd and following course, 8″ (1 brick) wide, headers in every sixth course. Side walls to be 8′ high from bottom of joists to top of plate, the two upper courses being brought out, half each, to the line of buttresses, so as to form a brick cornice. End walls to be for double pitch roof, 1 to 3, ridge 10′ 8″ above string course:

Door frame set in centre of one side so that top of sill may be 9″ above string course and ¼″ below floor when laid.

Two blind ventilators, 2½″ x 3″ section, in each end wall in first course above the floor ; outer opening 4′ from corner of building: inner opening 6″ nearer end walls, with right-angled turns connecting them to prevent possibility of thrusting anything through.

Wall strips, $2\frac{1}{4}''$ x $4\frac{1}{2}''$, projecting from wall $\frac{1}{4}''$ to $\frac{1}{2}''$ for attaching upright furring, built in around inside of building, one about 12″ from the floor, another same distance below plate.

Blind ventilator in each gable, same section as those above floor, but having outside opening 6″ above the inner one, instead of at one side.

Rafters, 3″ x 4″, built into each gable, flush with inside of wall.

After other rafters are in position, side walls carried up on inside above plate until they reach the sheathing.

All bricks to be well burnt, well laid and well pointed. The brick work as far up as the string course may be grouted.

Joists, 15 pieces, 3″ x 8″.

Flooring of good second quality, $1\frac{1}{4}''$ stuff, thoroughly dry, planed one side, tongued and grooved, and blind nailed so that no nails may be exposed.

Plate, $2\frac{1}{4}''$ x 4″, flush with inside of wall.

Intermediate rafters, 8 pieces 3″ x 6″, notched over plate so that upper side may be flush with edge of brick cornice; halved and well nailed at ridge.

Ties, 1″ x 8″, strongly nailed to each rafter and resting on plate.

Roof sheathing of good common 1″ boards, projecting 2″ on all sides of building.

Roofing of good tin plate, well laid either with diagonal turned or upright soldered seams, brought down around and under the projected sheathing so as to cover all woodwork of roof. Where obtainable, one layer of tarred roofing paper placed under the tin.

Furring of cheap culls 4″ x 1″ or 4″ x $\frac{3}{4}''$, about 6′ long and 4″ apart, to be nailed on each side of the wall strips.

not coming nearer than 6″ to floor, object being only to secure ventilation and prevent powder touching the brick walls.

Door frame, 3′ x 6′ 6″ clear. Sill of oak, maple or birch, 3″ x 9″ x 4′; planed on top and front, and top bevelled for 3″. Jambs of clear dry stuff, $1\frac{1}{2}$″ x 6″, planed and rabitted and well mortised into sill and cap flush with inside of building. False cap, $\frac{3}{4}$″ x $4\frac{1}{2}$″ gained or mortised into jambs. Cap of hard wood or good spruce, 3″ x 9″ x 5′, pinned to jambs and built into brickwork after wall has reached height of latter, planed where surface is exposed.

Door opening outward, in two leaves, either double diagonal or strong battened. May be advantageously covered with sheet iron 1-16″ to $\frac{1}{8}$″ thick. Good strong hinges. When shut, one leaf fastened to both cap and sill by strong bolts, the other by strong and well fastened rim lock, having two keys of unusual pattern. Brass trimmings are desirable but not essential.

Outside of metal roof painted with one coat best white lead and one of mineral paint; sill, cap and door with two coats of white lead, the second being tinted.

Considerable difference of opinion has existed regarding the danger from lightning. The Swiss Committee on the physical properties of dynamite (1870) reported that "thunderstorms and lightning involve no special danger to dynamite. . . . But if well confined, and if the temperature produced by the lightning be high enough, an explosion may possibly take place." Prof. Munroe severely criticises neglect of lightning protection, and suggests that "a network of metal rods carried over the tops of those magazines whose roofs are slated, and given a sufficient ground connection, would be a complete protection." Guttmann also insists on protection, and advocates an idea of Melsens. "It consists in surrounding the building either completely with a network of wires or in conducting along the roof-edges and corners of the building barbed wires which are earthed (grounded) at several places.[5] "In general it is agreed that the earth plate should be as large as possible and that it should be put either into water or into permanently moist soil, or, if neither of these be available, into a pit filled with coke."[6]

The distances allowed by the British law between magazines and other buildings, highways, etc.. is given somewhat abbreviated below.

Amt. of explosive to be allowed in magazine.	Distances to be kept clear from			
	Private railroad, highway, promenade or open place of resort for the public, canal dock, etc.	Any shop, magazine or store for explosives, furnace, kiln or fire for any use.	Public Railway	Dwelling house with written consent of owner.
500 lb	50 yards	100 yards	....	50 yards
1000 "	75 "	150 "	....	75 "
1 ton	100 "	200 "	....	100 "
2 "	102 "	200 "	215 yards	120 "
3 "	105 "	200 "	235 "	140 "
5 "	110 "	200 "	265 "	175 "
10 "	120 "	250 "	330 "	250 "
20 "	140 "	400 "	460 "	400 "
25 "	150 "	475 "	525 "	475 "

5 The Manufacture of Explosives, vol. ii., p. 375.

6 *Ibid* p. 373.

In an explosion near Chicago in 1886, the magazine containing 50 tons of black powder and 15 tons of dynamite, the brick and stone were thrown a distance of 1300 feet. This explosion was caused by a stroke of lightning. Greater safety may be obtained by either so placing a magazine that a hill or rise of ground is interposed between it and adjoining objects that may suffer from an explosion. If this is not possible a mound of earth or sand from 12 to 15 feet high, with its base 20 feet from the magazine, will deflect the force of the explosion upwards and will materially shorten the radius of danger in that direction.

For gunpowder the magazine should be fitted up with racks so that the kegs may be maintained in a slightly inclined position. Dynamite should be stored in tiers, box on box, with battens or lath between the successive layers of boxes to insure good ventilation and to lessen the danger from friction.

Gunpowder in unopened cases, dynamite in unopened boxes, and fuse securely boxed may be stored together in the same magazine, but no fulminates in the form of caps or otherwise, or loose coils of fuse should ever be stored in the same building with gunpowder and high explosives.

The building must be kept scrupulously clean, and men with nails exposed on the soles or heels of their boots should not enter or work in any magazine. No fire should be permitted in or about such a structure, and smoking is not to be tolerated in the vicinity of explosives.

It is advised by those having most experience in the storage of explosives that gunpowder kegs should be rolled over once every two or three weeks to prevent caking, and that cases of dynamite should be turned over once every two weeks. According to Mr. G. G Turner, one of the most experienced men in practical blasting operations in America, this is an economy, because it tends to keep the dynamite homogeneous in composition, so that it detonates better. This is not necessary while the dynamite remains frozen.

No keg of gunpowder, or box containing any other explosive, should ever be opened in the magazine. This may be allowed only in small buildings kept for this purpose, where a limited supply for immediate use is maintained. In such a building not over 200 lb. of any form of explosive should be kept at a time. The kegs or canisters of gunpowder should always be kept closed, after removing that needed for use. In the case of dynamites, it is best to unpack the total quantity at once, wipe off the sawdust, lay the cartridges on their sides upon planed board shelves, and then carefully remove all fragments of the original boxes and sawdust, which should be burned in the open. Such sawdust usually contains more or less nitroglycerine, unless the dynamite is in unusually perfect condition. Any oily stain on the cases indicates that nitroglycerine had leaked from the cartridges. The shelves must also be frequently inspected, and if any oily stain is observed, no matter how minute, it must be thoroughly washed with a saturated solution in water of ordinary carbonate of soda (sal soda, or "washing soda"). This destroys the nitroglycerine. The floor of this building should also be washed occasionally with such a solution. No fire of any kind should ever be permitted in this structure, but it may be warmed by steam pipes, provided the pipes are so placed that no explosive may ev r come into direct contact with them.

The taking of unopened boxes of dynamite into a mine is a most reprehensible practice, since proper cleanliness and the removal of the sawdust and fragments of the boxes is not so easy as it is from buildings above ground. Only dynamite cartridges from which the sawdust has been wiped and placed in clean boxes should be sent below.

The characteristics of good dynamite and gunpowder have been given in a previous chapter. It is always advisable, on receiving a fresh consignment of such explosives, to make an inspection to ascertain that it is in good order. The opening of one box or keg out of every ten will usually suffice to detect any serious deficiency. If not in good condition the manufacturers should be notified at once. If faulty it should then not be returned (for its shipment under such circumstances, especially in the case of nitroglycerine powders, is dangerous), but should be destroyed. For this purpose select a sufficiently isolated situation, and lay the dynamite cartridges on the ground, end to end in a line or very open spiral. Pour paraffine oil over the entire train, or if this is not available use kerosene, and ignite one end of the train with an ordinary fuse (of course not using a cap). It will burn quietly and safely. In cities where spent lime from gas purifiers is available, this may be used for the destruction of the nitroglycerine in the dynamite, though its decomposition is most readily accomplished with yellow ammonium sulphide.

Fuse in open coils should be stored separate from all other explosives, as should also be done with caps, detonators or exploders. They should be kept in a dry place, where there is freedom from fire or high temperatures.

Thawing Dynamite.

Dynamite should not be thawed by direct heat from a fire or a stove. There is also more or less peril of producing leakiness and starting decomposition by thawing it in the sun. There is peculiar peril from thawing it in the sun when the rays are transmitted through window glass, as imperfections in the glass are apt to focus the heat at certain points.

There are only two safe ways to thaw dynamite, viz., in a room heated by steam pipes, in which case the explosive must never be laid on the pipes, and in a vessel surrounded by warm water. The proper temperature of the water is 125° F., which is approximately the temperature at which the bare hand can just be held without pain. The water should be heated separately and poured into the water-space in the thawer, and the thawer should not be heated over a stove or other source of heat. The best material to use in making a thawer is sheet zinc, though the best grades of galvanized iron will do. All seams should be absolutely smooth, so as to leave no crevices for the lodgment of dirt and nitroglycerine. There are two forms of thawers made, one resembling a glue pot, or the farina boiler used in kitchens. The water space should be at least two inches wide between the inner vesse' containing the dynamite and the outer wall of the vessel holding the water. In some, the water vessel has an additional space in the outer wall for an asbestos lining to conserve the heat. A better form of thawer is one containing horizontal tubes large enough to receive the cartridges, the tubes extending through a square or rectangular water box. The water is poured in through a funnel mouth at the top, and drawn off through a faucet below. The advantage of this thawer is that the cartridges lie flat, so that there is less tendency to disturb the homogeneity of the dynamite.

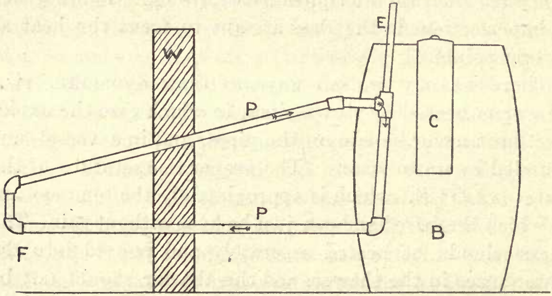

Fig. 2.

A third form which is recommended by Mr. Brainerd of the Hamilton Powder Co. for thawing large quantities of dynamite at a time consists of a barrel B (Fig 2) into which is fitted a pipe system P, with an expansion pipe E, containing water. This pipe system passes through a wall W, and the water in it is heated by a fire or stove at F. The barrel is filled with water, which is heated by the hot water circulating in the pipe system. A zinc or galvanized receptacle, C, for the dynamite, is suspended in the barrel.

In using any form of thawer the cartridges should be free from sawdust, and the vessel or tubes holding them should be kept scrupulously clean. The only way to make sure of maintaining a proper freedom from accumulations of nitroglycerine in the thawer is to wash it out after each thawing with a strong solution of carbonate of soda (sal soda, or washing soda), which is best applied warm.

Dynamite is never properly thawed while it feels lumpy at any part of the cartridge. It should be uniformly pliable throughout. Its use when but partially thawed is attended with danger in loading, and its detonation will be imperfect, with the consequent disadvantages of yielding a less powerful effect and giving off noxious fumes.

CHAPTER V.

BLASTING.

The subject of blasting has been very exhaustively and scientifically treated by Messrs. A. W. and Z. W. Daw, in a book designed for technical men.[1] A simpler treatise, with good practical suggestions, has been prepared by Oscar Guttmann.[2] There are few operations in mining where a workman can display a higher degree of skill and effect larger economies than in the proper placing of bore-holes, and in the proper adjustment of his charges to the work to be done. Against every hole fired is charged a number of expenses, to wit, labor, power (steam or air) where machine drills are used, wear and tear on plant, explosives, and also a general loss distributed among many items in the operation of the mine, if the output per miner falls below the estimated average, for the handling of which preparations have been made.

For the most part efficient work in blasting is a matter of experience and good judgment. This cannot be taught in books, but there are some general rules which are fundamental, and in proportion as these are understood and appreciated the work of mining will be conducted with greater system and economy. Unsystematic effort

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[1] The Blasting of Rock in Mines, Quarries, Tunnels, etc. New York, Spon and Chamberlain, 1898.

[2] Blasting: A Handbook for the use of Engineers and others engaged in Mining. Philadelphia, J. B. Lippincott Co., 1892.

is always wasteful and costly, and system implies the recognition of some definite principles according to which the work is laid out and prosecuted.

A few points of prime importance which should be observed are the following: First, the strength and quantity of the explosive should be properly proportioned to the cohesive strength or resistance of the rock.

Second, the "burden," or line of least resistance (*i. e.*, the shortest line that can be drawn from the charge in the bore-hole to the outer free face of the rock,) should bear a proper relation to the strength of the explosive and to the resistance of the rock.

Third, if the working face of the rock is so blasted as to leave two or more free faces instead of one for future blasts, the power required to overcome the resistance of the rock will be reduced, and explosives can be economized.

Fourth, a seam or fissure is a valuable aid in blasting if the hole is so located as to take advantage of this weakness, and, on the other hand, the power of the explosive may be expended along such a seam without doing useful work if the hole is improperly located.

Fifth, breaking to regular benches and faces is more economical than irregular breaking, because the condition of the rock can be more carefully observed, admitting of a more intelligent placing of subsequent bore-holes, and it facilitates the handling and setting up of machine drills. It is also more convenient for work by hand drilling, in addition to which it keeps the mine in better condition for a complete and economical extraction of the ore.

Sixth, simultaneous firing is more economical in most cases than firing singly or in series, for the reason that the adjacent charges assist each other, reducing the amount of explosive required and the total length of holes to be drilled for any given volume of rock.

Seventh, careful charging, so as to secure as highly compacted a charge as possible, greatly increases the efficiency of the explosive.

Eighth, a well prepared primer, in the case of high explosives, is the key to a successful detonation of the charge, on which, other things being equal, its efficiency depends.

Ninth, the efficiency of all explosives, including high explosives, is dependent to a considerable extent upon the kind, length and degree of compactness of the tamping.

Tenth, the object of blasting in mines and quarries is to rupture rock so that it may be removed, not to hurl it to a distance, *i. e.*, not to secure what military engineers call "ballistic" effect. Hence only enough explosive should be used to accomplish this. When fragments are thrown more than a few feet by a blast it is generally an evidence that the proper relation did not exist between the charge and the "burden," and that too large a charge was used for the length of the line of least resistance.

In the accompanying illustration (Fig. 3) B N is the bore-hole; W L, measured from the centre of the charge in the shortest possible line to the free face, is the line of least resistance, or "burden;" M N is the charge in the bore-hole, which should be about 12 times as long as the diameter of the hole at its bottom; R S K is the outline of the new face which will be produced after the blast. The best results are obtained when the line of least resistance is perpendicular to the line of the bore-hole. The line of least resistance must be shorter than the bore-hole, else the force of the explosion will expend itself in the direction of the bore-hole If black powder is used in such a case the charge will blow out the tamping, producing a "pop shot." If high explosives are used in this case the "crater," or funnel of rupture, will have very steep sides and a relatively small volume of rock will be ruptured.

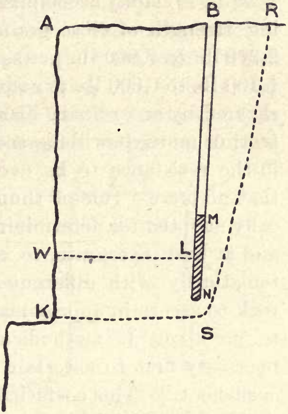

Fig. 3.

The forces to be overcome vary with the kind of rock, the number and position of the free faces, and the direction of the blast. The direction of the blast is determined by the direction of the line of least resistance. If this is upwards the explosion must overcome the cohesion of the rock plus the weight of the volume of rock ruptured. If downwards, the explosion has to overcome only the cohesive strength of the rock. A somewhat smaller charge may consequently be used. For each individual shot this difference is trifling, but in the aggregate it is an important quantity in practical operations. The rupture of rock in blasting is mainly accomplished by "shearing." The shearing strength of close grained granites varies from about 2,200 lb. to 2,900 lb. per square inch, and of marbles from 1,100 lb. to 1,600 lb. per square inch. As the total surface sheared by an ordinary blast is often as much as 73 square feet, or more, it will be seen how great is the difference in the resistance to be overcome in different cases, and that no mere "rule of thumb" method may be economically adopted for determining the charges. It is wasteful, and at best inaccurate, to continue experimenting unsystematically with different sizes of charges in any given rock to ascertain approximately the right one. It is better to go about it methodically. For this purpose it is necessary first to ascertain what is known as the "rock coefficient." This coefficient is the quotient obtained by dividing the weight in pounds of the charge found capable of just rupturing the rock by the cube (or third power) of the length of the line of least resistance used in the experimental blast. As the resistances vary with the number of free faces, it is best to determine the rock coefficient separately for the different conditions in practical work. For example, if a tunnel is to be driven the conditions will be as follows: With each new "cut" there will be a certain number of "bearing in" shots to "unkey" the face. In this case the coefficient should be determined for the rock with one free face. The "enlarging shots," after unkeying, will have two, and in some cases three free faces. It will suffice to determine the co-efficient in these cases for the rock with two free faces. The method to be pursued will be sufficiently explained by describing the procedure for obtaining the rock coefficient with two free faces.[3] Select a bench of the rock in which blasting is to be conducted, about two feet wide on top and three feet high. In this drill four or five holes of the diameter to be adopted in regular work in future, three feet deep, so that the line of least resistance will in each case be two feet long. The holes should be bored as far apart as three times the length of the line of least resistance, so that the shots will not influence each other by opening up seams. The rock must be selected where it is homogeneous, so that all the shots will be fired under exactly similar conditions. Now charge the several holes with different weights of the explosive, beginning with a quantity so small as not to effect rupture, and increasing by regular amounts to a charge which will be more than sufficient. Select the blast which has produced the desired effect as the one by which to determine the coefficient. If this hole was charged with $\frac{5}{8}$ lb. (0.625 lb.) of dynamite,

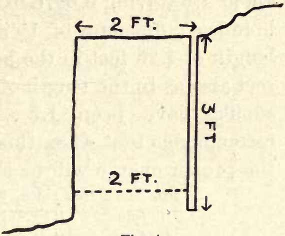

Fig. 4.

[3] This gives what Daw calls the charging coefficient. Daw's method is more scientific, determining the rock coefficient and charging coefficient separately, but is not so easily applicable by the common miner. The method here given leads to sufficiently accurate results in practical work.

then the rock coefficient is $\frac{0.625}{2^3\ (=8)} = 0.0781$. The charge to be used in future blasts is found by multiplying the cube of the length in feet of the line of least resistance by this coefficient. For instance, in this rock, a line of least resistance $2\frac{3}{4}$ feet long would require $2.75^3\ (=20.797) \times 0.0781 = 1.624$ lb. of dynamite. As the specific gravity of well-compacted high-grade dynamite is about 1.6 (giving 0.0576 lb, per cu. in.), and as the bore hole has a diameter of $1\frac{1}{2}$ inch, the charge will occupy a length of 1.25 feet in the hole. This is approximately correct also as to the length of charge in the bore-hole, which should have been $1.5 \times 12 = 18$ inches. Guttmann recommends that when there are more than two free faces the proper charge will be the following:

For three	free sides,	$\frac{2}{3}$	of the	calculated charge.
" four	"	$\frac{1}{2}$	"	"
" five	"	2-5	"	"
" six	"	$\frac{1}{3}$ [4]	"	"

The economy in simultaneous firing will vary with the strength of the rock, but on an average it may be said to save about 25 per cent. of explosive. The economy of boring, under the best conditions, will amount to about 24 per cent. This depends on the distance apart of the bore-holes. For very strong compact rock the distance between holes in simultaneous firing should be at least twice the length of the line of least resistance; for average strong rock, $1\frac{1}{2}$ to 2 times; for moderately strong rock, from the same length as the line of least resistance to $1\frac{1}{2}$

4 This last is the case presented in "block-holing," or blasting isolated blocks needing but one charge.

times that distance ; and for weak rock only the length of the line of least resistance.

The lines of least resistance should be proportional to the diameter of the bore-holes. The following table is given by M. Eissler :

No.	Diameter of Bore-Holes.		
	$1\frac{1}{4}$ in.	$1\frac{1}{2}$ in.	$1\frac{3}{4}$ in.
	Lines of Least Resistance.		
1	$3\frac{1}{2}$ ft.	4 ft.	5 ft.
2	$3\frac{3}{4}$ ft.	5 ft.	6 ft.
3	5 ft.	6 ft.	7 ft.

The corresponding depths of bore-holes in the above, as stated by Eissler, are, for No. 1, equal to the line of least resistance ; for No. 2, $1\frac{1}{2}$ times that length, and for No. 3, twice that length.

Charging Holes with Dynamite.

Instructions have been given under Fulminates and Fuses (Chap. II.) for attaching the cap and fuse, or electric detonator, to cartridges. The cartridge thus prepared is called the "primer." The several cartridges constituting the charge are inserted first, and care must be taken to have the bore-hole of such a size that they may pass freely to the bottom without binding. It should never be necessary to force them to the bottom. In order that they may be compressed to fill the entire width of the hole the cartridge paper must be cut lengthwise. This is best done with a copper blade. To do so with a steel knife is not unattended with danger. The cartridges should now be firmly compressed with a *wooden* rammer, but they must never be rammed Firm pressure only is allowable. *No steel or iron instrument must ever be used in charging any kind of explosive in a bore-hole.* The cartridges must be so well compressed upon each other that no air spaces may remain between them. This would produce an air cushion, and if it did not cause a portion of the charge to escape explosion, would at least prevent perfect detonation, weakening the effect of the explosive. The primer is inserted last. The cartridge paper, as previously explained, should be tied firmly above the cap with a string, one end of which should be long enough to admit of lowering the primer into the hole with it To lower the cartridge by the fuse or wires is apt to loosen the cap, and thus an air cushion will be formed below it, reducing the power of the explosion. Carelessness in regard to this simple detail is one of the commonest causes of waste in the use of dynamite. *The primer must never be compressed or rammed upon the charge.* The "tamping" is now put in. Many writers advocate the use of sand or water with dynamite in holes inclining downwards. The most experienced blasters, however, state very positively that better results are always obtained by using the same clay tamping as is required with black powder. Tamping should be absolutely free from gritty particles. The best material is clay, damp enough to merely retain its form when compressed into a ball in the hand. Pellets of this should be dropped into the hole and very lightly compressed with a wooden rammer until about six inches of the hole above the charge has been filled. From this point to the top the tamping may be more firmly compressed, but not rammed.

Charging Holes with Black Powder.

After removing the sludge, dry the hole with a wisp of hay, or a rag, or cotton waste, fastened to the end of a rod. Now pour in the powder through a copper or tin funnel with a long stem, so that the powder will reach the bottom of the hole without touching its sides above the limit of the charge. If the hole is horizontal a long scoop may be used, filled with powder, which at the end of the hole is turned round to deposit the charge. For either horizontal holes, or those inclined upwards, the powder may be put into small paper bags and closely pressed into the end. For wet holes waterproof cartridges must be made, as explained in Chapter II. The fuse is now put into place, and in the case of holes filled with powder in bags the last bag should have the fuse tied into it. Dry clay is now pressed over the charge, followed by the ordinary damp clay tamping, pressed firmly for three inches, after which it may be rammed by tapping the end of the tamping stick with a hammer. In holes one inch in diameter the charge will not blow out 7 inches of good tamping. With a diameter of two inches, 18 inches of tamping will not blow out. With a diameter of three inches, 20 inches of tamping will not blow out. These are the lowest limits admissable. An excess should always be given. The amount of the charge has nothing to do with it. The determining factor is the diameter of the hole. "Expansion tamping," so called, is employed with black powder when it is desired to cause its action to be retarded so as to split the rock along lines of weakness without shattering. It is consequently of value in quarrying. This consists in filling several inches of the hole above the charge with hay, straw, or tow, after which several inches of damp clay tamping are lightly compressed upon it, followed by firmly compressed tamping to the top. By "reaming" the holes so that a V notch is cut on each side the entire length of the hole, making the vertices of the angles of all the V notches lie in a straight line, as shown in Fig. 5, a perfectly homogenous rock may be split with extreme accuracy in any direction, using expansion tamping. Very small charges, of one to three ounces, will do astonishingly effective work under such circumstances. This is known as the Knox system. The use of the "needle" or "pricker" is so undesirable that no description of it will be given. The "barrel," or tube, may be used where the hole is wet. A copper tube is slipped over a wire, and the two are inserted together into the hole; the tamping is compressed around the

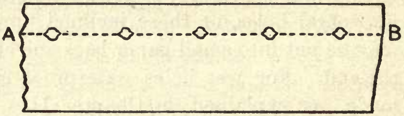

Fig. 5.

tube, and the wire is then withdrawn, being replaced by the fuse. The tube is recovered after the blast. For electric firing of black powder low-power fulminating caps are employed. It is erroneously stated by many that the power of the black powder is increased by the use of the fulminating cap, *i. e.*, that it is detonated. Under special conditions it is claimed that gunpowder can be detonated, but it is even questionable whether true detonation is accomplished when the gunpowder has absorbed some nitroglycerine, though apparently in the Judson powder this result is reached. Consequently there is no advantage in the use of strong detonators with common black powder.

Double primers, that is, two primers in one charge of high explosives, are advocated by some, when firing by electricity. In this case the first primer is placed at the bottom of the charge, and the subsequent cartridges carefully compressed upon it. This practice is not to be recommended except when carried out by men of the best experience.

Mis-Fires.

A constant source of danger arises from holes which have missed fire. Never be in a hurry to examine such a hole under any circumstances. When the firing is done by electricity, a half hour should be allowed ; when with fuse, wait several hours. It is best then to loosen up the fuse if possible, retreat quickly, and wait again a few minutes. If no explosion occurs, then proceed to withdraw the tamping with a copper or wooden spoon. Never use iron or steel for this purpose. In the case of high explosives, or of black powder which had been primed with a cap or detonator, remove the tamping to within about 3 inches of the charge, and no closer. Then recharge above this with a large charge of dynamite, and detonate in the ordinary way. If black powder and fuse had been used, withdraw all the tamping, recharge above the old charge, and fire. If dynamite is available, except in quarrying blocks, where this procedure might entail losses of valuable stone, it is safer to explode such a missed hole of black powder with a dynamite primer, which must not be compressed before firing. In general the use of two kinds of explosive in the same hole is a practice to be most strenuously condemned.

Adaptation of Explosives.

Adaptation of explosives to the kind of work to be done is of the utmost importance. Dynamites are not suitable for quarrying except where rubble is being obtained. Only the lowest power (40 per cent.) should then be used. Black powder is the best material for quarrying, although it is claimed that the lower power of joveite develops its explosive effect with sufficient slowness to be adapted to such uses. Also for certain ores, which contain galena and other minerals which may be too highly pulverized by high explosives, a slow acting powder is essential. High explosives pulverize and shatter ; black powder fractures. The higher the power of the dynamite the larger is the sphere of pulverization. For railroad work, and for "dead work" in mines, such as shaft sinking and tunnel driving, it is advantageous to use the higher grades of powders, such as 60 per cent. and 75 per cent. dynamites, and their equivalents in other forms of high explosives.

Chambering.

The bore-holes we have been considering are round, and slightly tapering toward the bottom. These are suited to blasting in homogeneous rock. In tough material, such as highly kaolinized felspathic rocks, or in clay banks, and in rocks which are extensively cross-fissured (*e.g.*, many felsites) in which latter the gas pressure from the explosion is partly relieved by merely expanding the seams or fissures, it is necessary to employ larger concentrated charges instead of the "extended charge" of an ordinary bore-hole. The commonest method of chambering, or making an enlarged cavity, is to detonate in the end of the hole a small charge of 60 per cent. or 75 per cent. dynamite, using a treble-force detonator, and no tamping. Into the chamber thus produced the charge is filled in the regular way. In the case of short fissured rocks this method often fails. It is then necessary to enlarge the cavity with a special tool, called an expanding bit, made for this purpose.

Bank Blasting.

Bank blasting is practised in breaking up large masses of more or less firmly cemented gravel in hydraulic mining, so as to admit of washing it out with a monitor. For this purpose black powder and Judson powder are most commonly employed, although any slow powder will serve, as much as 50,000 lb. being sometimes exploded in one blast. From 10 to 20 lb. of black powder are required for each 1,000 cubic yards of gravel. Although the method must be adapted to the local conditions, it may be said in general that a drift should be run in at the bottom of the bank, with a length equal to the height of the bank, or a shaft should be sunk at a distance from the edge of the bank equal to its height. A cross drift is then driven at the end of this excavation, forming a T, the cross of the T being also of the same length as the height of the bank. Kegs of powder are then piled upon each other in each end of the cross drift, every tenth keg having its head removed. A train of kegs, with the heads off, are placed in the drift to its center, where the primer is located, or a dynamite primer may be inserted in each keg in the train, all connected in series for instantaneous electric firing. When a single central primer is used, it consists of a box into which about 200 lb. of powder are placed, with several dynamite primers inserted into it, their detonators being connected in series for firing. The space above the large primer is now tamped tightly with debris, and the leading wires are laid to the surface. The drift or shaft is now tightly filled with clay and gravel, so as to make a firm tamping. The charge is then fired by a powerful battery.[5]

[5] For further details on this subject see "A Practical Treatise on Hydraulic Mining," by A. J. Bowie ; New York, D. Van Nostrand Co., 1889, and a paper on the Simultaneous Ignition of Thousands of Mines, by Julius H. Striedinger, in the Transactions of the American Society of Civil Engineers, New York, June, 1877.

Locating Bore-holes.

The general principles governing the placing of shot-holes have already been stated. It only remains to explain the method of procedure in special cases. In blasting to benches in homogeneous massive (*i.e.* unstratified) rock, the bore-hole should be exactly as long as the intended height of the bench. If the charge, the diameter of the hole and the line of least resistance are properly proportioned, the rock will break in an approximately perfect bench form. If the rock is stratified (Fig. 6), the hole should be bored short of the bedding plane C D. The force of the explosion will tend to relieve itself along this plane; hence the length of the charge in the bore-hole must be proportioned to the relation subsisting between the thickness of the stratum and the length of line of least resistance. The diameter of the hole, as shown before, depends upon its length. The reduction in the length of the charge, M, calculated in the ordinary way, is regulated as follows, T being the thickness of the stratum, M the calculated length of charge, M_1

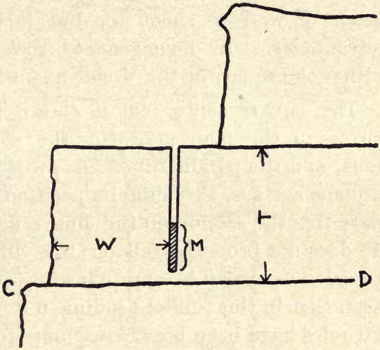

Fig. 6.

the reduced length, and w the line of least resistance[6]:

When $t=w$	$m_1=\frac{1}{2}m.$
" $t=1\frac{1}{4}\,w$	$m\ =\frac{5}{8}\,m.$
" $t=1\frac{1}{2}\,w$	$m_1=\frac{3}{4}\,m.$
" $t=1\frac{3}{4}\,w$	$m_1=\frac{7}{8}\,m.$
" $t=2\,w$	$m_1=m.$

In shaft sinking or tunnel driving, if there is a persistent joint, or seam, advantage can be taken of it for the "unkeying" or "breaking-in" shots. These can then be set deeper, so as to break out a "key" to the full depth of each cut, with a minimum of explosive. This is a "side cut." A side cut can be used where there is no seam or wall to shoot to, but it offers no particular advantages. In homogeneous rock the "center cut," either the square or the V-cut, is most commonly adopted.

The square center cut is shown in Fig 7, the small circles in the plan indicating the commencement of the hole, and the parallel lines the projection of the hole on a plane surface, revealing its position. To further elucidate this the section on the line A B is given. Hole No. 18 does not properly fall on this line, but its relative position as shown is approximately accurate. It will be seen that in this tunnel heading, 6 ft. wide and 7 ft. high, 20 holes have been bored, reaching to a distance of 3 ft. 3 in. from the face, which is the length of the cut. The "breaking in" or unkeying shots are Nos. 1, 2, 3 and 4, converging to a point. It is not undesirable if these holes unite, forming one chamber at the point. Thus by means of the concentration of the charge towards and at the

[6] A.W. and Z.W. Daw.

point the large resistance of the rock is overcome, in spite of the somewhat lengthy line of least resistance for blasting to only one free face. These must be fired simultaneously. The "following" or "enlarging" shots, 16 in number, are so placed as to be fired in either two or three successive volleys. The plan most economical of powder would be to fire 5, 7, 9 and 11 in the second volley; 6, 8, 10 and 12 in the third, and 13, 14, 15, 16, 17, 18, 19 and 20 in the fourth. Conditions, however, might render it more economical to use larger charges in holes 6, 8, 10 and 12, and include them in the same volley with 5, 7, 9 and 11. All the enlarging shots are breaking to two free faces, being nearly the equivalent of bench blasting, and they all have relatively short lines of

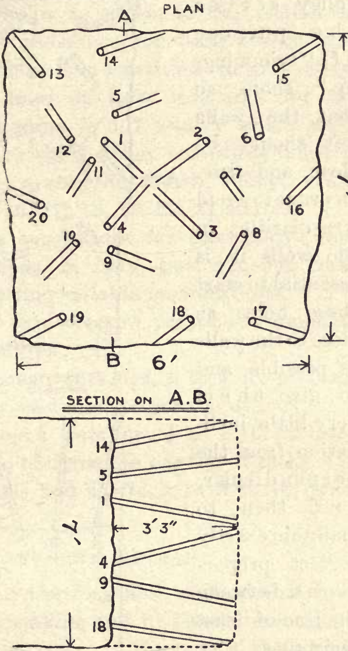

Fig. 7.

least resistance, properly proportioned to the depth of the holes. The last volley serves the purpose of "trimming-up" shots, so that the walls left should be clean and true. In order to avoid irregularities in the walls it is essential to start these holes as close to the walls as possible, and to give them very little inclination from the perpendicular, and then to maintain exactly correct proportions between the line of least resistance, the diameter of the hole and the charge used.

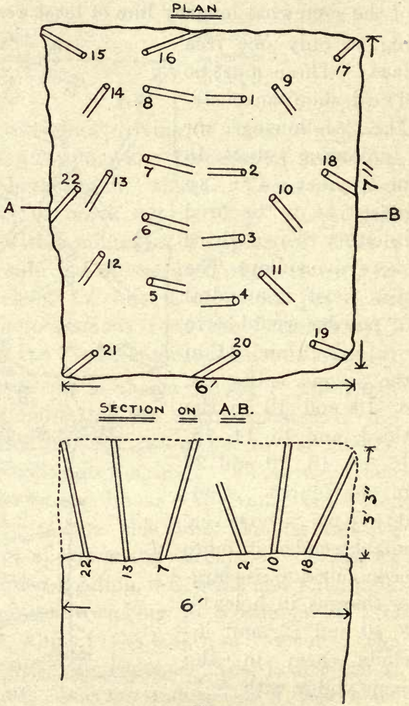

Fig. 8.

V-Shaped Center Cut.

In Fig. 8 is shown the V-cut, which offers two advantages. There are fewer dry holes to be bored, and the "key" can be broken out with smaller charges, since 1, 2, 3, and 4 are short holes, as appear in the section on A B, the line of least resistance for these being correspondingly short. These four constitute the first volley, and provide shorter lines of least resistance for the remaining breaking-in shots, 5, 6, 7 and 8, which make the second volley. The third volley comprises holes 9, 10, 11, 12, 13 and 14; and the fourth volley, which trims up, includes 15, 16, 17, 18, 19, 20, 21 and 22.

These will serve as suggestions for economical work under normal conditions in hard homogeneous rock, special conditions requiring suitable modifications.

The consumption of explosives in practice is found to be approximately as follows:

For small blasts in open workings, $\frac{1}{4}$ to $\frac{1}{2}$ lb. of black powder, and $\frac{1}{16}$ to $\frac{1}{8}$ lb. of dynamite per ton of rock.

For large blasts in open workings, $\frac{1}{6}$ to $\frac{1}{2}$ lb. of black powder, and $\frac{1}{24}$ to $\frac{1}{8}$ lb. of dynamite per ton of rock.

For headings, tunnels and shafts, $\frac{1}{2}$ to 2 lb. of dynamite per ton of rock.

The Long-hole Method.

Deep bore holes, or the long-hole method, has been adopted in both shaft sinking and in bench blasting, in open cuts and in large stopes. In the case of shaft sinking a series of diamond drill holes are bored to the full depth of the shaft, and filled with sand. A sufficient depth is left empty to receive a charge of 75 per cent. dynamite, and the holes are fired simultaneously. Then sand is spooned out to make room for another cut, and so on to the bottom Although the line of least resistance coincides with the line of the bore-hole, this disadvantage is offset by the use of the high-power dynamite, and by the great saving of time and cost in drilling. In adapting this method to bench blasting holes are drilled as deep as convenient in parallel rows, filled with sand as before, and successive slices are then blasted off. Where conditions render this system capable of adoption it affords highly economical results.

APPENDIX A.

Examples of Causes of Accidents.

The following examples have been selected from the Annual Report for 1898 of the Inspectors of Explosives of Great Britain.

Blasting Gelatine.	Killed.	Injured
About 1 lb. being thawed in a tin over a watchman's fire	2	2
A quarryman carrying cartridges and detonator in the same hand	......	1
Four holes had been charged, each with a cartridge and primer, and fired in the usual manner. All the shots were heard to go off. In removing the débris an explosion occurred. The gelignite was properly thawed. Supposed that one of the primers failed to detonate the charge	......	2
Hole too small for cartridge. Explosion occurred in pressing down the first cartridge with a wooden rammer	......	1
A quarryman forced cartridge into a hole with an iron bar	......	1
Two cartridges put into a hole, and forced down with an iron bar	......	1
Clearing away débris after a blast. Struck portion of unexploded cartridge	......	1
Pressing cartridge into a hole with a piece of drill steel	1	

Blasting Gelatine.—*Con.*	Killed.	Injured.
Cartridge was exploded by ramming into bore-hole. The weather was too cold for this explosive, and it was probably near the freezing point, and hence sensitive	......	1
Ramming cartridge with steel drill.......	1	1
Deepening a hole which had been fired and had not done its work	......	1
Block-holing. Charge had failed to go off. Workman returned to relight the fuse, when the explosion occurred	1	
Testing the end of a hole after a blast with an iron bar, to see if any of the charge remained	......	3
Testing hole in same manner after a blast in a shaft	......	5
Dynamite.		
Forcing primer into hole with a wooden rammer	......	1
Miners returned after 20 minutes to investigate cause of mis-fire	......	2
Ramming in the first ball of tamping clay.	......	1
Gunpowder.		
A hole had missed fire. Two days later a man started driving a wedge near the hole when the charge exploded	......	1
Using a short fuse to hasten explosion. The charge exploded before the workman could retreat	1	

GUNPOWDER.—*Con.*	Killed.	Injured.
Smoking a pipe while charging a hole	......	3
Loading a hole with the aid of an iron stemmer	1	1
Firing a charge in a hole to clear it of water, and immediately reloading	......	2
Powder lodged in a seam of rock in a quarry. Accidentally ignited	1	
Ramming charge in hole with an iron crow-bar	1	
Drilling out a mis-fire shot with a blunt drill	......	1
Tamping a charge with an iron bar	......	2
Forcing a cartridge into too small a hole	......	5

DETONATORS.	Killed.	Injured.
Attempting to withdraw a wire from an electric detonator	......	1
Attaching a fuse to a detonator carelessly	......	1
Detonator found in débris. Tapped it to see if it was good	......	1
Trying to destroy a detonator by striking it with a stone	......	1
Holding an electric detonator in a gas flame	......	2
Trod on a detonator. Exploded 800 other detonators in the same room	2	2
Pricking the composition in the detonator with a pin	......	1
Spark from miner's lamp fell into box containing fuse and caps	1	

Accidents in Thawing Dynamite.	Killed.	Injured.
Some cartridges being thawed on a stove in the weigh-house	2	
Thawing cartridges in front of a kitchen fire	1	6
Thawing dynamite on a shovel	......	1
Cartridges placed near a fire to thaw	2	
Cartridges placed in an oven to thaw	1	2
Hot-water thawer containing dynamite placed on blacksmith's fire	1	2
Thawing dynamite with a candle	......	1
Warming dynamite over blacksmith's fire	2	
Thawing dynamite in water over a fire	2	
Heating dynamite in a tin over a candle	1	1
Reheating some water which had been used in a dynamite thawer, 3 accidents	2	4
Six similar explosions recorded	6	6
Rubbing cartridge in hands to complete thawing	......	1
Thawing dynamite over a candle, 2 accidents	1	1
Cartridge left in pocket of trousers which were hung before fire to dry	1	
Total number of accidents from thawing for 1898 was 81, the casualties being	68	97
All other accidents, 194	52	216
Totals	120	313

The accidents from explosives reported in Ontario for 1899 are as follows :

Dynamite	Killed.	Injured.
Forced cartridge into too small a hole, or used iron pipe as tamping rod........	1	
Drilling in or near missed hole	3	
Charged hole, lit fuse, went short distance, came back and shoved piece of wood in hole just as charge exploded.........	......	1
Thawing dynamite before open fire in blacksmith's forge..................	1	1
Totals.........................	5	2

APPENDIX B.

Important Books on Explosives.

Blasting: A Handbook for the Use of Engineers and Others Engaged in Mining, Tunnelling, Quarrying, etc. Oscar Guttmann. Philadelphia : J. B. Lippincott Co., 1892.

Blasting of Rock in Mines, Quarries, Tunnels, etc. A. W. and Z. W. Daw. New York : Spon and Chamberlain, 1898.

Explosives and their Power. M. P. E. Berthelot. Trans. from the French by Napier Hake and William McNab. London : John Murray, 1892.

Explosifs Modernes. P. F. Chalon. Paris : E. Bernard et Cie., 1889.

Geschichte der Explosivstoffe. S. J. von Romocki. Two volumes. Berlin : Robert Oppenheim, 1895.

Handbook of Modern Explosives. M. Eissler. London: Crosby, Lockwood and Son, 1890.

Index to the Literature of Explosives Part I. Charles E. Munroe. Baltimore: Isaac Friedenwald, 1886.

—— ditto. Part II. Baltimore: Deutsch Lithographing and Printing Co., 1893.

Lectures on Explosives. Willoughby Walke. New York: John Wiley and Sons, 1897.

Manufacture of Explosives. Oscar Guttmann. Two volumes. London: Whittaker and Co., 1895.

APPENDIX C.

Regulations for the Storage and Handling of Explosives in Ontario.

From the Act to amend the Mines Act, 63 V. c. 13.

3. No magazine of powder, dynamite or other explosive shall be erected or maintained at a nearer distance than four hundred feet from the mine and works, except with the written permission of the Inspector, and every such magazine shall be constructed of materials and in a manner to ensure safety against explosion from any cause, and shall be either so situated as to interpose a hill or rise of ground higher than the magazine between it and the mine and works, or else an artificial mound of earth as high as the magazine, and situated not more than 30 feet from it shall be so interposed.

4. No powder, dynamite or other explosive shall be stored underground in a working mine in excess of a supply for 48 hours, and in no case shall more than 100 pounds be so stored on one level. It shall be kept in securely covered boxes, and located in otherwise unused parts of the mine never less than 10 feet from lines of

underground traffic, nor less than 150 feet from places where drilling and blasting are carried on, and the temperature of such place shall never be less than 60 degrees F. nor more than 125 degrees F.

5. No fuse, blasting caps, electric detonators or any articles containing iron or steel shall be stored in the same magazine, box or other receptacle with powder, dynamite or other explosive, nor at a less distance than 50 feet from such magazine, box or receptacle.

6. Whenever a workman opens a box containing an explosive, or when he in any manner handles the same, he shall not permit any lighted lamp or candle to come closer than five feet to such explosive, nor permit said lamp or candle to be in such a position that the air current may convey sparks to the explosive, and a workman shall not approach nearer than five feet to an open box containing an explosive with a lighted lamp, candle, pipe or any other thing containing fire.

7. A thorough daily inspection shall be made of the condition of stores of explosives in a mine, and it shall be the duty of the manager, captain or other officer in charge of the mine to institute an immediate investigation when an act of careless placing or handling of explosives is discovered by or reported to him ; and any employee who commits a careless act with an explosive or where explosives are stored, or who having discovered it omits or neglects to report immediately such act to an officer in charge of the mine shall be guilty of an offence against this Act.

8. A proper apparatus, approved by the Inspector, shall be provided for use in every mine for thawing explosives, and shall be employed under the direction of the mine foreman, or of careful and experienced workmen.

9. In charging holes for blasting, no iron or steel tool or rod shall be used, and no iron or steel shall be used in any hole containing explosives.

10. A charge which has missed fire shall not be withdrawn, but shall be blasted ; and in case the missed hole has not been blasted at the end of a shift, the fact shall be reported by the foreman or shift "boss" to the next relay of miners before work has been commenced by them. To facilitate the blasting of such charge, in cases where the depth of hole and length of charge are known, the tamping may be removed with a copper or wooden instrument to within three inches of the charge in order to insert a new primer for exploding it.

11. All drill holes, whether sunk by hand or machine drills, shall be of sufficient size to admit of the free insertion to the bottom of the hole of a stick or cartridge of powder, dynamite or other explosive without ramming, pounding or pressure.

12. No powder, dynamite or other explosive shall be used to blast or break up ore in roast heaps where by reason of the heated condition of such ore or otherwise there is any danger or risk of premature explosion of the charge.

34. All oils and other inflammable materials shall be stored or kept in a building erected for that purpose, and at a safe distance from the powder magazine and from the main buildings, and their removal from said building for use shall be in such quantities only as are necessary to meet the requirements of one day.

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