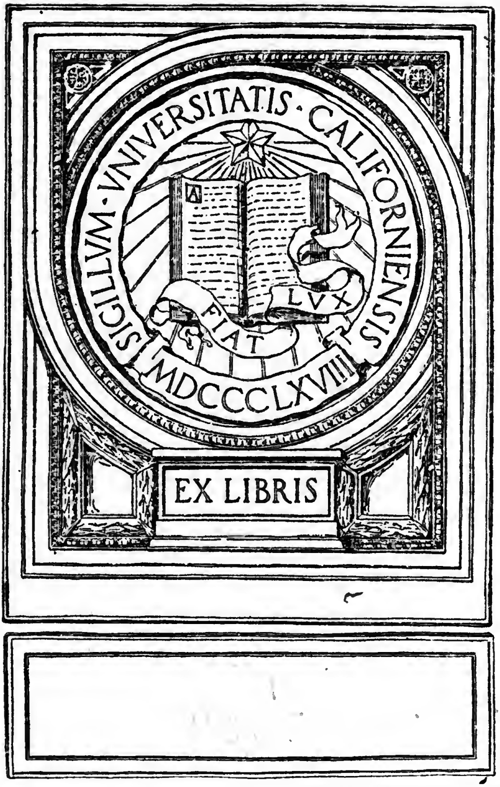

ROCK BLASTING.

ROCK BLASTING.

A

PRACTICAL TREATISE

ON THE

MEANS EMPLOYED IN BLASTING ROCKS

FOR INDUSTRIAL PURPOSES.

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PREFACE.

DURING the past decade, numerous and great changes have taken place in the system followed and the methods adopted for blasting rocks in industrial operations. The introduction of the machine drill led naturally to these important changes. The system which was suitable to the operations carried on by hand was inefficient under the requirements of machine labour, and the methods which had been adopted as the most appropriate in the former case were found to be more or less unsuitable in the latter. Moreover, the conditions involved in machine boring are such as render necessary stronger explosive agents than the common gunpowder hitherto in use, and a more expeditious and effective means of firing them than that afforded by the ordinary fuse. These stronger agents have been found in the nitro-cotton and the nitro-glycerine compounds, and in the ordinary black powder improved in constitution and fired by detonation; and this more expeditious and effective means of firing has been discovered in the convenient application of electricity. Hence it is that the changes mentioned have been brought about, and hence, also, has arisen a need for a work like the present, in which the subjects are treated of in detail under the new aspects due to the altered conditions.

GEO. G. ANDRÉ.

LONDON, 17, KING WILLIAM STREET, STRAND,
January 1*st*, 1878.

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ROCK BLASTING.

CHAPTER I.

THE TOOLS, MACHINES, AND OTHER APPLIANCES USED IN BLASTING ROCKS.

SECTION I.—HAND BORING.

Drills.—The operations of blasting consist in boring suitable holes in the rock to be dislodged, in inserting a charge of some explosive compound into the lower portion of these holes, in filling up, sometimes, the remaining portion of the holes with suitable material, and in exploding the charge. The subjects which naturally first present themselves for consideration are: the nature, form, and construction of the tools, machines, and other appliances used. Of these tools, the "drill" or "borer" constitutes the chief. To understand clearly the action of the rock drill, we must consider the nature of the substance which has to be perforated. He who has examined the mineral constitution of rocks will have recognised the impossibility of *cutting* them, using that term in its ordinary acceptation, inasmuch as the rock constituents are frequently harder than the material of the tools employed to penetrate them. As a rock cannot be cut, the only way of removing portions of it is to fracture or to disintegrate it by a blow delivered through the medium of a suitable instrument. Each blow so delivered may be made to chip off a small fragment, and by this means the rock may be gradually worn away. To effect this chipping, however, the instrument used must present only a small surface to the rock, in order to concentrate the force, and that surface must be bounded by inclined planes or wedge surfaces, to cause a lateral pressure upon the particles of rock in contact with them. In other words, the instrument must be provided with an edge similar to that possessed by an ordinary *cutting* tool.

The conditions under which the instrument is worked are obviously such that this edge will be rapidly worn down by attrition from the hard rock material, and by fracture. To withstand these destructive actions, two qualities are requisite in the material of which the instrument is composed, namely, hardness and toughness. Thus there are three important conditions concurring to determine the nature and the form of a cutting tool to be used in rock boring—1, a necessity for a cutting edge; 2, a necessity for a frequent renewal of that edge; and 3, a necessity for the qualities of hardness and toughness in the material of the tool.

In very hard rock, a few minutes of work suffice to destroy the cutting edge, and then the tool has to be returned to the smithy to be re-sharpened. Hence it is manifest that the form of the edge should not be one that is difficult to produce, since, were it so, much time would be consumed in the labour of re-sharpening. Experience has shown that the foregoing conditions are most fully satisfied in the steel rod terminating in a simple chisel edge, now universally adopted.

FIG. 1.

This form of drill is exhibited in Fig. 1, which represents a common "jumper" borer. It consists of a rod terminating at each end in a chisel edge, and having a swell, technically described as the "bead," between the extremities to give it weight. The bead divides the jumper into two unequal portions, each of which constitutes a chisel bit, with its shank or "stock." The shorter stock is used while the hole is shallow, and the longer one to continue it to a greater depth.

With the jumper, the blow is obtained from the direct impact of the falling tool. The mode of using the instrument is to lift it with both hands to a height of about a foot, and then to let it drop. In lifting the jumper, care is taken to turn it partially round, that the edge may not fall twice in the same place. By this means, the edge is made to act most favourably in chipping away the rock, and the hole is kept fairly circular. So long as the holes are required to be bored vertically downwards, the jumper is a convenient and very efficient tool, and hence in open quarrying operations, it is very commonly employed. But in mining, the shot-holes are more often required to be bored in some other direction, or, as it is termed, "at an angle;" that is, at an angle with the vertical. Or it may be that a shot-hole is required to be bored vertically upward. It is obvious that in any one of these directions the jumper is useless. To meet the requirements of such cases, recourse is had to the hammer wherewith to deliver the blow, and the drill is constructed to be used with the hammer. We have a suitable form of tool for application in this wise when we cut out the bead of the jumper and leave the ends flat for a striking face, as shown in Figs. 2 and 3. The form of the two chisels thus obtained is that adopted for the ordinary rock drill.

FIG. 2.

FIG. 3.

It will be understood from these descriptions that a rock drill consists of the chisel edge or *bit*, the *stock*, and the *striking face*. Formerly drills were made of wrought iron, and steeled at each end to form the bit and the striking face. Now they are commonly made of cast steel, which is supplied for that purpose in octagonal bars of the requisite diameter. The advantages offered by steel stocks are numerous. The superior solidity of texture of that material renders it capable of transmitting the force of a blow more effectively than iron. Being stronger than the latter material, a smaller diameter of stock, and, consequently, a less weight, are sufficient. This circumstance also tends to increase the effect of the blow by diminishing the mass through which it is transmitted. On the other hand, a steel stock is more easily broken than one of iron.

The cutting edge of a drill demands careful consideration. To enable the tool to free itself readily in the bore-hole, and also to avoid introducing unnecessary weight into the stock, the bit is made wider than the latter; the difference in width may be as much as 1 inch. It is evident that in hard rock, the liability of the edge to fracture increases as the difference of width. The edge of the drill may be straight or slightly curved. The straight edge cuts its way somewhat more freely than the curved, but it is weaker at the corners than the latter, a circumstance that renders it less suitable for very hard rock. It is also slightly more difficult to forge. The width of the bit varies, according to the size of the hole required, from 1 inch to 2½ inches. Figs. 4, 5, and 6 show the straight and the curved bits, and the angles of the cutting edges for use in rock.

The stock is octagonal in section; it is made in lengths varying from 20 inches to 42 inches. The shorter the stock the more effectively does it transmit the force of the blow, and therefore it is made as short as possible. For this reason, several lengths are employed in boring a shot-hole, the shortest being used at the commencement of the hole, a longer one to continue the depth, and a still longer one, sometimes, to complete it. To ensure the longer drills working freely in the hole, the width of the bit should be very slightly reduced in each length. It has already been remarked that the diameter of the stock is less than the width of the bit; this difference may be greater in coal drills than in rock or "stone" drills; a common difference in the latter is $\frac{3}{8}$ of an inch for the longer. The following proportions may be taken as the average adopted:—

FIG. 4.

FIG. 5.

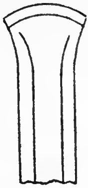
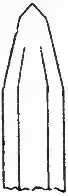


FIG. 6.



Width of the Bit.	Diameter of the Stock.	Width of the Bit.	Diameter of the Stock.
1 inch	$\frac{5}{8}$ inch	$1\frac{3}{4}$ inch	$1\frac{1}{8}$ inch
$1\frac{1}{8}$ "	$\frac{3}{4}$ "	2 inches	$1\frac{3}{8}$ "
$1\frac{1}{4}$ "	$\frac{7}{8}$ "	$2\frac{1}{4}$ "	$1\frac{1}{2}$ "
$1\frac{1}{2}$ "	1 "	$2\frac{1}{2}$ "	$1\frac{5}{8}$ "

The striking face of the drill should be flat. The diameter of the face is less than that of the stock in all but the smallest sizes, the difference being made by drawing in the striking end. The amount of reduction is greater for the largest diameters; that of the striking face being rarely more than one-eighth of an inch.

The making and re-sharpening of rock drills constitute an extremely important part of the labour of the mine smith. The frequent use of the drill, and its rapid wear, necessitate a daily amount of work of no trifling proportions, and the judgment and skill required in proper tempering render some degree of intelligence in the workman indispensable; indeed, so much depends upon the smith whose duty it is to repair the miners' tools, that no pains should be spared to obtain a man capable of fulfilling that duty in the most efficient manner possible.

When the borer-steel bars are supplied to the smith, he cuts them up, as required, into the desired lengths. To form the bit, the end of the bar is heated and flattened out by hammering to a width a little greater than the diameter of the hole to be bored. The cutting edge is then hammered up with a light hammer to the requisite angle, and the corners beaten in to give the exact diameter of the bore-hole intended. As the drills are made in sets, the longer stocks will have a bit slightly narrower than the shorter ones, for reasons already given.

The edge is subsequently touched up with a file. In performing these operations, heavy hammering should be avoided, as well as high heats, and care should be taken in making the heat that the steel should be well covered with coal, and far enough removed from the tuyere to be protected from the "raw" air. Overheated or "burned" steel is liable to fly, and drills so injured are useless until the burned portion has been cut away.

Both in making and in re-sharpening drills, great care is required to form the cutting edge evenly, and of the full form and dimensions. If the corners get hammered in, as shown in Fig. 7, they are said to be "nipped," and the tool will not free itself in cutting. When a depression of the straight, or the curved, line forming the edge occurs, as shown in Fig. 8, the bit is said to be "backward," and when one of the corners is too far back, as in Fig. 9, it is spoken of as "odd-cornered." When either of these defects exist—and they are unfortunately common—not only does the bit work less effectively on the rock, but the force of the blow is thrown upon a portion

Fig. 7.

Fig. 8.

Fig. 9.

only of the edge, which, being thereby overstrained, is liable to fracture.

The hardening and tempering of steel is a matter requiring careful study and observation. It is a well-known fact that a sudden and great reduction of temperature causes a notable increase of hardness in the metal. The reason of this phenomenon is not understood, but it is certain that it is in some way dependent upon the presence of carbon. The degree of hardness imparted to steel by this means depends upon the amount of the reduction of the temperature, and the proportion of carbon present in the metal, highly carburetted steel being capable of hardening to a higher degree, under the same conditions, than steel containing less carbon. Thus, for steel of the same quality, the wider the range of temperature the higher is the degree of hardness. But here we encounter another condition, which limits the degree of hardness practically attainable.

The change which takes place among the molecules of the metal in consequence of the change of temperature causes internal strains, and thereby puts portions in a state of unequal tension. This state renders the strained parts liable to yield when an additional strain is thrown upon them while the tool is in use; in other words, the brittleness of the steel increases with its hardness. Here again the proportion of carbon present comes into play, and it must be borne in mind that for equal degrees of hardness the steel which contains the least carbon will be the most brittle. In hardening borer-steel, which has to combine as far as possible the qualities of hardness and toughness, this matter is one deserving careful attention. It is a remarkable fact, and one of considerable practical value, that when oil is employed as the cooling medium instead of water, the toughness of steel is enormously increased.

The tempering of steel, which is a phenomenon of a similar character to that of hardening, also claims careful consideration. When a bright surface of steel is subjected to heat, a series of colours is produced, which follow each other in a regular order as the temperature increases. This order is as follows: pale yellow, straw yellow, golden yellow, brown, brown and purple mingled, purple, light blue, full clear blue, and dark blue. Experience has shown that some one of these colours is more suitable than the rest for certain kinds of tools and certain conditions of working.

The selection of the proper colour constitutes a subject for the exercise of judgment and skill on the part of the smith. For rock drills, straw colour is generally the most suitable when the work is in very hard rock, and light blue when the rock is only of moderate hardness.

The processes of hardening and tempering drills are as follows: When the edge of the bit has been formed in the manner already described, from 3 to 4 inches of the end is heated to cherry redness, and dipped in cold water to a depth of about an inch to harden it. While in the water, the bit should be moved slightly up and down, for, were this neglected, the hardness would terminate abruptly, and the bit would be very liable to fracture along the line corresponding with the surface of the water. In cold weather, the water should be slightly warmed, by immersing a piece of hot iron in it, before dipping the steel. When a sufficient degree of hardness has been attained, the remainder of the hot portion is immersed until the heat is reduced sufficiently for tempering. At this stage it is withdrawn, and the colours carefully watched for. The heat which is left in the stock will pass down to the edge of the bit, and as the temperature increases in that part the colours will appear in regular succession upon the filed surface of the edge. When the proper hue appears, the whole drill is plunged into the water and left there till cold, when the tempering is complete. When the edge is curved or "bowed," the colours will reach the corners sooner than the middle of the bit. This tendency must be checked by dipping the corners in the water, for otherwise the edge will not be of equal hardness throughout. As the colour can be best observed in the dark, it is a good plan to darken that portion of the smithy in which tempering is being carried on.

The degree of temper required depends upon the quality of the steel and the nature of the work to be performed. The larger the proportion of carbon present in the metal, the lower must be the temper. Also the state of the blunted edges, whether battered or fractured, will show what degree of hardness it is desirable to produce. From inattention to these matters, good steel is not unfrequently condemned as unsuitable.

To form the striking face, the end of the stock is heated to a dull red, and drawn out by a hammer to form a conical head. The extremity is then flattened to form a face from ½ inch to 1 inch in diameter. This head is then annealed to a degree that will combine considerable toughness with hardness. The constant blows to which the head is subjected tend to wear it down very rapidly. There is great difference in the lasting qualities of steel in this respect; some drills will wear away more quickly at the striking than at the bit end.

A smith will, with the assistance of a striker, sharpen and temper about thirty single-hand drills of medium size in an hour, or twenty double-hand drills of medium size in the same time. Of course, much will depend on the degree of bluntness in the cutting edge; but assuming the drills to be sent up only moderately blunted, this may be taken as a fair average of the work of two men.

It will be evident from the foregoing remarks, that to enable a drill to stand properly it must be made of good material, be skilfully tempered in the smithy, and provided with a cutting edge having an angle and a shape suited to the character of the rock in which it is used. To these conditions, may be added another, namely, proper handling; for if the drill be carelessly turned in the hole so as to bring all the work upon a portion only of the cutting edge, or unskilfully struck by the sledge, fracture or blunting will speedily result. Improper handling often destroys the edge in the first five minutes of using.

Drills, as before remarked, are used in sets of different lengths. The sets may be intended for use by one man or by two. In the former case, the sets are described as "single-hand" sets, and they contain a hammer for striking the drills; in the latter case, the sets are spoken of as "double-handed," and they contain a sledge instead of a hammer for striking. It may appear at first sight that there is a waste of power in employing two men, or, as it is termed, the double set, for that two men cannot bore twice as fast as one. This rate of speed can, however, be obtained, and is due less to the greater effectiveness of the stroke than to the fact that two men can, by repeatedly changing places with each other, keep up almost without intermission a succession of blows for an indefinite length of time; whereas, with the single set, the man is continually obliged to cease for rest.

Hammers.—To deliver the blow upon a rock drill, hammers and sledges are used. The distinction between a hammer and a sledge is founded on dimensions only: the hammer being intended for use in *one* hand, is made comparatively light and is furnished with a short handle, while the sledge, being intended for use in *both* hands, is furnished with a much longer handle and is made heavier. The striking face of the blasting sledge should be flat, to enable the striker to deliver a direct blow with certainty upon the head of the drill; and to facilitate the directing of the blow, as well as to increase its effect, the mass of metal composing the head should be concentrated within a short length. To cause the sledge to fly off from the head of the drill in the case of a false blow being struck, and thereby to prevent it from striking the hand of the man who holds the drill, the edges of the striking face should be chamfered or bevelled down till the diameter is reduced by nearly one-half. This requirement is, however, but seldom provided for.

The head of a sledge is of iron; it consists of a pierced central portion called the "eye," and two shanks or "stumps," the steeled ends of which form the striking faces or "panes." The form of the head varies in different localities, but whatever the variations may be, the form may be classed under one of four types or "patterns." A very common form is that shown in Fig. 10 and known as the "bully" pattern. By varying the width, as shown in Fig. 11, we obtain the "broad bully," the former being called for the sake of distinction the "narrow" bully. Another common form is the "pointing" pattern, represented in Fig 12. The form shown in Fig. 13 is designated as the "bloat" pattern; and that given in Fig. 14 the "plug" pattern. Each of these forms possesses peculiar merits which

FIG. 10.

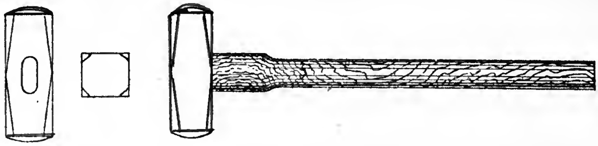


FIG. 11.

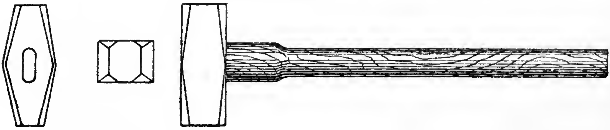


FIG. 12.

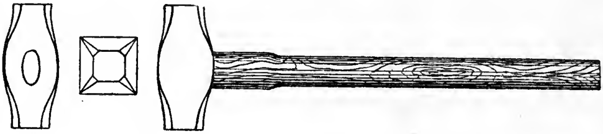
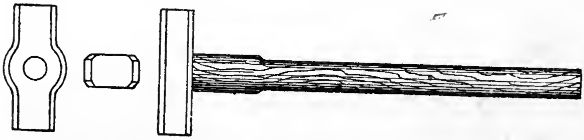


FIG. 13.



renders it more suitable for certain uses than the others. The same forms are used for hammers. The eye is generally made oval in shape, but sometimes, especially with the bloat pattern, it is made circular, as shown in Fig. 13. The weight of a sledge head may vary from 5 lb. to 10 lb., but a common and convenient weight is 7 lb. The length of the helve varies from 20 inches to 30 inches; a common length for blasting sledges is 24 inches. The average weight of hammer heads is about 3 lb., and the average length of the helve 10 inches.

FIG. 14.

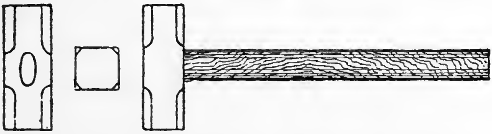


Fig. 15 represents a blasting sledge used in South Wales. The stumps are octagonal in section, and spring from a square block in the centre. The panes or striking faces, however, are circular and flat. The length of the head is $8\frac{3}{4}$ inches, and that of the helve 27 inches, and the weight of the tool complete 7 lb.

FIG. 15.

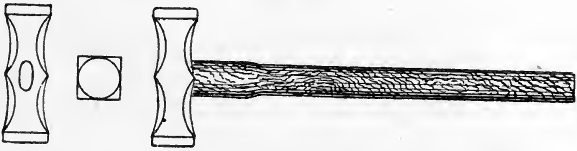
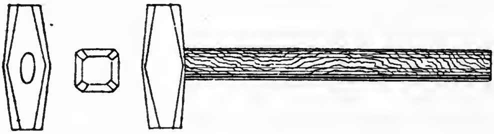


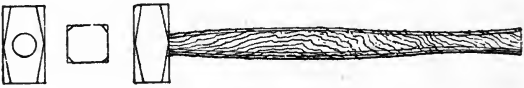
Fig. 16 represents a blasting sledge used in North Wales. The central block is an irregular octagon in section, formed by slightly chamfering the angles of a square section, and the stumps are chamfered down to form a regular octagon at the panes, which are flat. The length of the head is 7¾ inches, and that of the helve 22 inches, and the weight of the tool complete 6 lb. 7 oz.

FIG. 16.



The sledges used in the north of England have shorter heads, and are lighter than the foregoing. Fig. 17 represents one of these blasting sledges.

FIG. 17.



The head is nearly square in section at the centre, and the panes are flat. The length of the head is 5 inches, and that of the helve 24½ inches, and the weight of the sledge complete 4 lb. 14 oz.

Auxiliary Tools.—Besides the drill and the hammer, other tools are needed in preparing the hole for the blasting charge. If the bore-hole is inclined downwards, the débris or "bore-meal" made by the drill remains on the bottom of the hole, where it is converted into mud or "sludge" by the water there present. This sludge has to be removed as the work progresses, to keep the rock exposed to the action of the drill. The removal of the sludge is effected by a simple tool called a "scraper." It consists of a rod of iron from ¼ inch to ½ inch in diameter, and of sufficient length to reach the bottom of the bore-hole. One end of the rod is flattened out on the anvil and made circular in form, and then turned up at right angles to the stem. The disc thus formed must be less in diameter than the bore-hole, to allow it to pass readily down. When inserted in the hole, the scraper is turned round while it is being pressed to the bottom; on withdrawing the instrument, the sludge is brought up upon the disc. The operation, two or three times repeated, is sufficient to clear the bore-hole. The other end of the scraper is sometimes made to terminate in a ring for convenience in handling, as shown in Fig. 18. Instead of the ring, however, at one end, a disc may be made at each end, as shown in Fig. 19, the discs in this case being of different diameter, to render the scraper suitable for different size bore-holes. Sometimes the

Fig. 18.

Fig. 19.

scraper is made to terminate in a spiral hook or "drag-twist," as represented in Fig. 20. The use of the drag is to thoroughly cleanse the hole before inserting the charge. A wisp of hay is pushed down the hole, and the drag end of the scraper introduced after it, and turned round till it has become firmly entangled. The withdrawal of the hay by the drag wipes the bore-hole clean. Instead of the twist drag, the "loop" drag is frequently employed. This consists of a loop or eye, through which a piece of rag or tow is passed. The rag or tow is used for the same purpose as the hay, namely, to thoroughly cleanse and dry the bore-hole previous to the introduction of the charge. Very frequently the "swab-stick" is used instead of the scraper to clear out the bore-hole. This is simply a deal rod bruised at one end by blows with a hammer until the fibres separate to form a kind of stumpy brush or "swab." When this is pushed down the hole, the sludge passes up around and between the fibres, which are then spread out by being pressed against the bottom of the hole. On withdrawing the swab, the sludge is brought out with it.

FIG. 20.

When the charge has been placed in the bore-hole, and the fuse laid to it, the hole needs to be tamped, that is, the portion above the charge has to be filled up with some suitable substance. For this purpose, a "rammer," "stemmer," or "tamping iron," as the instrument is variously called, is required. This instrument is illustrated in Fig. 21. It consists of a metal bar, the tamping end of which is grooved to receive the fuse lying against the side of the bore-hole. The other end is flat, to afford a pressing surface for the hand, or a striking face for the hammer when the latter is needed. To prevent the danger of accidental ignition from sparks caused by the friction of the metal against silicious substances, the employment of iron stemmers has been prohibited by law. They are usually made of copper or phosphor-bronze, the latter substance being more resisting than the former.

FIG. 21.

FIG. 22.

Sometimes in wet ground it becomes necessary to shut back the water from the bore-hole before introducing the charge of gunpowder. This happens very frequently in shaft sinking. The method employed in such cases is to force clay into the interstices through which the water enters. The instrument used for this purpose is the "claying-iron" or "bull," represented in Fig. 22. It consists of a round bar of iron, called the stock or shaft, a little smaller in diameter than the bore-hole, and a thicker portion, called the head or poll, terminating in a striking face. The lower end of the shaft is pointed, to enable it to penetrate the clay, and the head is pierced by a hole about an inch in diameter to receive a lever. Clay in a plastic state having been put into the bore-hole, the bull is inserted and driven down by blows with the sledge. As the shaft forces its way down, the clay is driven into the joints and crevices of the rock on all sides. To withdraw the bull, a bar of iron is placed in the eye and used as a lever to turn it round to loosen it; the rod is then taken by both hands and the bull lifted out. To allow the bull to be withdrawn more readily, the shaft should be made with a slight taper and kept perfectly smooth. As the bull is subjected to a good deal of heavy hammering on the head, the latter part should be made stout. This tool, which should be considered as an extra instrument rather than as an essential part of a blasting set, is a very serviceable one, and should always be at hand in wet ground when loose gunpowder is employed.

Another instrument of this auxiliary character is the beche, Fig. 23, used for extracting a broken drill. It consists of an iron rod of nearly the diameter of the bore-hole, and hollow at the lower end. The form of the aperture is slightly conical, so that the lower end may easily pass over the broken stock of the drill,

FIG. 23.

and, on being pressed down with some force, may grasp the stock in the higher portion of the aperture with sufficient firmness to allow of the two being raised together. When only a portion of the bit remains in the hole, it may often be extracted by means of the drag-twist end of the scraper, or the swab-stick may be driven down upon the broken portion, and latter withdrawn with the swab.

Sets of Blasting Gear.—On Plates I., II., and III., will be found three sets of blasting gear; a set of coal-blasting gear; a set of single-hand stone-blasting gear; and a set of double-hand stone-blasting gear. In the first set, the drill, shown in Fig. 1, is 22 inches in length; the cutting edge is straight and 1½ inch wide, and the weight is 2½ lb. The other drill, Fig. 2, is 42 inches in length; it has a straight cutting edge 1 7/16 inch wide, and weighs 4 lb. 10 oz. The hammer used in this set and shown in Fig. 3 weighs 2 lb. 14 oz.; the length of the head is 4½ inches, and that of the handle 7¾ inches. In the second or single-hand stone set, the shorter drill, Fig. 6, Plate II., is 22 inches in length; the cutting edge is strongly curved, and is 1½ inch in width, and the weight is 3 lb. 10 oz. The longer drill, Fig. 7, is 36 inches in length; the width of the cutting edge, which is curved as in the shorter drill, is 1 7/16 inch, and the weight is 6 lb. 5 oz. The hammer used with this set, and represented in Fig. 8, weighs 3 lb. 6 oz.; the length of the head is

5 inches, and that of the handle 10 inches. In the third or double-hand stone set, Plate III., the first or shortest drill, Fig. 12, is 18 inches in length, $1\frac{3}{4}$ inch wide on the cutting edge, and weighs $4\frac{1}{4}$ lb. The second drill, Fig. 13, is 27 inches in length, $1\frac{11}{16}$ wide on the cutting edge, and weighs 6 lb. The third or longest drill, Fig. 14, is 40 inches in length, $1\frac{5}{8}$ inch wide on the cutting edge, and weighs $9\frac{1}{4}$ lb. The cutting edges of all these drills are strongly curved as in the preceding set. The sledge used with this set, and represented in Fig. 15, weighs about 5 lb.

SECTION II.—MACHINE BORING.

Machine Rock-Drills.—The most remarkable advance, which in recent, or perhaps in any, times has been made in the practice of mining consists in the substitution of machine for hand labour in rock boring. The importance of this change is obvious, and very great. Not only is the miner relieved thereby of the labour of boring, but the speed with which the shot-holes may be bored is increased a hundredfold. This gain of speed offers many practical advantages. The ability to sink a shaft or to drive a heading rapidly may ensure the success of an undertaking, and save indirectly the expenditure of large sums of money; and, in all cases, it allows the time spent in preparatory work to be materially shortened. Indeed, it would be difficult to over-estimate the magnitude of the advantage accruing from the increased rate of progress due to the substitution of machine power for hand labour, and in the future we may expect to see its application greatly extended. In making this substitution, numerous difficulties have had to be overcome, and in encountering these many failures have had to be recorded. But it must now be conceded by the most prejudiced that rock-boring machines have successfully passed through what may be described as the tentative stage of their existence, and have taken a foremost place among the mechanical appliances which experience has shown to be capable of effectually performing the work required of them. In the author's work on 'Mining Engineering,' the requirements of a rock drill will be found fully discussed, and the principles and the construction of the most important machines now in use carefully explained and described. In the present work, only one example can be given.

Machine drills penetrate rock in the same way as the ordinary hand drills already described, namely, by means of a percussive action. The cutting tool is in most cases attached directly to the piston rod, with which it consequently reciprocates. Thus the piston with its rod is made to constitute a portion of the cutting tool, and the blow is then given by the direct action of the steam, or the compressed air, upon the tool. As no work is done upon the rock by the back stroke of the piston, the area of the forward side is reduced to the dimensions necessary only to lift the piston, and to overcome the resistance due to the friction of the tool in the bore-hole. The piston is made to admit steam or air into the cylinder, and to cut off the supply, and to open the exhaust, as required, by means of tappet valves, or other suitable devices; and provision is made to allow, within certain limits, a variation in the length of the stroke. During a portion of the stroke, means are brought into action to cause the piston to rotate to some extent, for the purposes that have been already explained. To keep the cutting edge of the tool up to its work, the whole machine is moved forward as the rock is cut away. This forward or "feed" motion is usually given by hand, but in some cases it is communicated automatically. The machine is supported upon a stand or framing which varies in form according to the situation in which it is to be used. This support is in all cases constructed to allow of the feed motion taking place, and also of the cutting tool being directed at any angle. The support for a rock drill constitutes an indispensable and a very important adjunct to the machine, for upon the suitability of its form, material, and construction, the efficiency of the machine will largely depend.

The foregoing is a general description of the construction and mode of action of percussive rock-drills. The numerous varieties now in use differ from each other rather in the details of their construction than in the principles of their action, and the importance of the difference is, of course, dependent upon that of the details. It is but just to remark here that the first really practical solution of the rock-drilling problem is due to M. Sommeiller, whose machine was employed in excavating the Mont Cenis tunnel.

The Darlington Drill.—The machine which, in England, has stood the test of experience most satisfactorily, and which, consequently, is surely working itself into general favour in this country, and also in some of the important mining districts of the Continent, is the invention of John Darlington, and is known as the "Darlington drill." This drill is remarkable as the attainment of the highest degree of simplicity of parts possible in a machine. The valve gear of a machine drill is especially liable to derangement. It must necessarily consist of several parts, and these parts must as necessarily be of a somewhat fragile character. Besides this, when actuated by the piston through the intervention of tappets, the violence of the blow delivered at each stroke is such as to rapidly destroy the parts. In some machines, the force of these blows and their destructive tendency have been reduced to a minimum; but when every means of remedying the evil has been employed, there remains a large amount of inevitable wear and tear, and a liability to failure from fracture or displacement exists in a greater or less degree. Moreover, as these effects are greatly intensified by increasing the velocity of the piston, it becomes at least undesirable to use a high piston speed. To remedy these defects, which are inherent in the system, Darlington proposed to remove altogether the necessity for a valve gear by radically changing the mode of admitting the motor fluid to the cylinder. This proposal he has realized in the machine which is illustrated on Plate IV.

The Darlington rock-drill consists essentially of only two parts: the cylinder A, Figs. 20 and 21, with its cover; and the piston B, with its rod. The cover, when bolted on, forms a part of the cylinder; the piston rod is cast solid with the piston, and is made sufficiently large at its outer end to receive the tool. These two parts constitute an engine, and with less than one fixed and one moving part it is obviously impossible to develop power in a machine by the action of an elastic fluid. The piston itself is made to do the work of a valve in the following manner: The annular space affording the area for pressure on the fore part of the piston gives a much smaller extent of surface than that afforded by the diameter of the cylinder, as shown in the drawing; and it is obvious that by increasing or diminishing the diameter of the piston rod, the area for pressure on the one side of the piston may be made to bear any desired proportion to that on the other side. The inlet aperture, or port C, being in constant communication with the interior of the cylinder, the pressure of the fluid is always acting upon the front of the piston, consequently when there is no pressure upon the other side, the piston will be forced backward in the cylinder. During this backward motion, the piston first covers the exhaust port D, and then uncovers the equilibrium port E, by means of which communication is established between the front and back ends of the cylinder, and, consequently, the fluid is made to act upon both sides of the piston. The area of the back face of the piston being greater than that of the front face by the extent occupied by the piston rod, the pressure upon the former first acts to arrest the backward motion of the piston, which, by its considerable weight and high velocity, has acquired a large momentum, and then to produce a forward motion, the propelling force being dependent for its amount upon the difference of area on the two sides of the piston. As the piston passes down, it cuts off the steam from the back part of the cylinder and opens the exhaust. The length or thickness of the piston is such that the exhaust port D is never open to its front side, but, in the forward stroke, it is opened almost immediately after the equilibrium port is closed, and nearly at the time of striking the blow. It will be observed that the quantity of fluid expended is only that which passes over to the back face of the piston, since that which is used to effect the return stroke is not discharged.

The means employed to give a rotary motion to the tool are deserving of special attention, as being simple in design, effective in action, and well situate within the cylinder. These means consist of a spiral or rifled bar H, having three grooves, and being fitted at its head with a ratchet wheel G, recessed into the cover of the cylinder. Two detents J, J, Fig. 22, also recessed into the cover, are made to fall into the teeth of the ratchet wheel by spiral springs. These springs may, in case of breakage, be immediately renewed without removing the cover. It will be observed that this arrangement of the wheel and the detents allow the spiral bar H to turn freely in one direction, while it prevents it from turning in the contrary direction. The spiral bar drops into a long recess in the piston, which is fitted with a steel nut made to accurately fit the grooves of the spiral. Hence the piston, during its instroke, is forced to turn upon the bar; but, during its outstroke, it turns the bar, the latter being free to move in the direction in which the straight outstroke of the piston tends to rotate it. Thus the piston, and with it the tool, assumes a new position after each stroke.

The mode of fixing the cutting tool to the piston rod is a matter deserving some attention. As the tool has to be changed more than once during the progress of a bore-hole, it is important that the change should be accomplished in as short a time as possible; and as the vibration of the machine and the strain upon the tool are necessarily great, it is equally important that the tool be firmly held. It is also desirable that the mode of fixing the tool shall not require a shoulder upon the latter, a slot in it, or any peculiarity of form difficult to be made in the smithy. The Darlington machine fulfils the requirements of expedition in fixing, firmness of retention, and simplicity of form most satisfactorily. The means and the method are the following: The outer end of the rod or holder is first flattened to afford a seat for the nut, as shown in Figs. 21 and 25. The slot is then cut and fitted tightly with a piece of steel K forged of the required shape for the clamp, and the holder is afterwards bored to receive the tool while the clamp is in place. This clamp K is then taken out, its fittings eased a little, and its end screwed and fitted with a nut. When returned to its place in the holder, the clamp, in consequence of the easing, can be easily drawn tight against the tool, by which means it is firmly held in position. The shank of the tool is turned to fit the hole easily, and the end of it is made hemispherical to fit the bottom of the hole, upon which the force of the reaction of the blow is received.

It would seem impossible to attain a higher degree of simplicity of form, or to construct a machine with fewer parts. The absence of a valve or striking gear of any kind ensures the utmost attainable degree of durability, and allows a high piston speed to be adopted without risk or injury. As the piston controls its own motion, there is no liability to strike against the cylinder cover. The stroke may be varied in length from half an inch to four inches, and as the machine will work effectively with a pressure of 10 lb. to the inch, holes may be started with the greatest ease. With a pressure of 40 lb., the machine makes 1000 blows a minute, a speed that may be attained without causing undue strains or vibration. This alone constitutes a very great advantage. It must indeed be conceded that an unprejudiced consideration of the merits of this drill shows it to be admirably adapted to the work required of it.

Borer-Bits.—The form and the dimensions of the cutting tools, variously described as "drills," "borers," and "bits," used with machine rock-perforators are matters of great practical importance. The dimensions are determined mainly by two conditions, namely, the necessity for sufficient strength in the shank of the tool, and the necessity for sufficient space between the shank and the sides of the hole to allow the débris to escape. Experience has shown that the latter condition is best fulfilled when the distance between the sides of the hole and the shank of the tool is from $\frac{3}{16}$ inch to $\frac{1}{4}$ inch, regard being had to the former condition.

The form of the cutting edge is determined by several conditions, some of which have been already discussed in relation to hand drills. The form first adopted was naturally that possessed by the hand drill, namely, the chisel edge. To increase the useful effect of the blow, the cutting edge was subsequently doubled, the bit being formed of two chisel edges crossing each other at right angles. This bit, which from its form was called the "cross" bit, was found to penetrate the rock more rapidly than the straight or chisel bit. The gain in speed was very marked at the commencement of the hole; but it diminished gradually as the hole progressed in depth, owing to the difficulty with which the débris escaped. To remedy this defect, the cutting edges were next made to cross each other obliquely, so as to form the letter X. In this way, the two chisel edges were retained, while the breadth of the bit was considerably reduced. This form, described as the X bit, cleared the hole much more effectively than the cross, but not in a manner that was altogether satisfactory. Another modification of the form was, therefore, made, and this time that of the Z was adopted, the upper and the lower portions of which were arcs of circles struck from the centre of the bit in the direction contrary to that of the rotation.

This form of tool, which is known as the Z bit, readily cleared itself of the débris. But besides this advantage, it was found to possess others of an important character. With the chisel-edge forms, the corners of the bit were rapidly worn off by friction against the sides of the hole. With the

Z form, this wearing no longer occurred, by reason of the large surface exposed to friction. Another advantage of the Z form of bit lies in its tendency to bore the hole truly circular. Generally then, it may be stated that this form satisfies most fully the determining conditions. The form of bit, however, that is most suitable in a given case will, in some degree, be determined by particular circumstances. Of these, the nature and the character of the rock will operate most strongly to influence the choice. Thus the cross bit will generally be found the most suitable in fissured rock, while the single chisel edge may be used with advantage in rock of a very solid and hard character. Indeed, on the judicious selection of the most suitable form of cutting edge, the success of machine boring largely depends. The chisel bit, the cross bit, the X bit, and the Z bit, are shown in Figs. 24 to 27.

FIG. 24.

FIG. 25.

FIG. 26.

FIG. 27.

The sharpening of bits of a form other than that of the chisel is done by means of "swages." The tempering is effected in the way already described in reference to hand drills. As in the latter case, the degree of temper must be suited to the hardness of the rocks to be penetrated. Generally the straw colour will be found to be the best degree. It is a remarkable fact that the wear of the cutting edge of a machine drill is, for a given length of boring, five or six times less than that of a hand drill. Steel of the best quality should always be used.

As in the case of hand boring, each successive length of drill must diminish slightly in the width of its cutting edge; a diminution of about $\frac{1}{32}$ inch may be considered sufficient. Care should, however, be taken to ensure the proper dimensions being given to the edge, and it will be found advantageous to have at hand an accurate gauge through which the tool may be passed previously to its being fixed to the machine. It is important that the tool be truly "centred," that is, the centres of the edge of the bit, of the shank, and of the piston rod, should be perfectly coincident.

Rock-Drill Supports.—A machine rock-drill may satisfy every requirement, and yet, by reason of the defective character of the support to which it is attached, it may be unsuitable to the work required of it. Hence it becomes desirable to carefully study the design and construction of a drill support, and to consider the requirements which it is needful to fulfil. Assuming the necessity for a high degree of strength and rigidity in the support, a primary condition is that it shall allow the machine to be readily adjusted to any angle, so that the holes may be bored in the direction and with the inclination required. When this requirement is not fulfilled, the machine is placed, in this respect, at a great disadvantage with hand labour. If a machine drill were not capable of boring in any position and in any direction, hand labour would have to be employed in conjunction with it, and such incompleteness in the work of a machine would constitute a serious objection to its adoption.

Besides allowing of the desired adjustment of the machine, the support must be itself adjustable to uneven ground. The bottom of a shaft which is being sunk, or the sides, roof, and floor of a heading which is being driven, present great irregularities of surface, and, as the support must of necessity in most cases be fixed to these, it is obvious that its design and construction must be such as will allow of its ready adjustment to these irregularities. The means by which the adjustment is effected should be few and simple, for simplicity of parts is important in the support as well as in the machine, and for the same reasons. A large proportion of the time during which a machine drill is in use is occupied in shifting it from one position or one situation to another; this time reduces, in a proportionate degree, the superiority of machine over hand labour, in respect of rapidity of execution, and it is evidently desirable that it should be shortened as far as possible. Hence the necessity for the employment of means of adjustment which shall be few in number, rapid in action, and of easy management.

For reasons similar to the foregoing, the drill support must be of small dimensions, and sufficiently light to allow of its being easily portable. The limited space in which rock drills are used renders this condition, as in the case of the machine itself, a very important one. It must be borne in mind that, after every blast, the dislodged rock has to be removed, and rapidity of execution requires that the operations of removal should be carried on without hindrance. A drill support that occupies a large proportion of the free space in a shaft or a heading is thus a cause of inconvenience and a source of serious delay. Moreover, as it has to be continually removed from one situation to another, it should be of sufficiently light weight to allow of its being lifted or run along without difficulty. In underground workings, manual power is generally the only power available, and therefore it is desirable that both the machine and its support should be of such weight that each may be lifted by one man. Of course, when any endeavour is made to reduce the weight of the support, the necessity for great strength and rigidity must be kept in view.

In spacious headings, such as are driven in railway tunnel work, supports of a special kind may be used. In these situations, the conditions of work are different from those which exist in mines. The space is less limited, the heading is commenced at surface, and the floor is laid with a tramway and sidings. In such a case, the support may consist of a more massive structure mounted upon wheels to run upon the rails. This support will carry several machines, and to remove it out of the way when occasion requires, it will be run back on to a siding; but for ordinary mining purposes, such a support is suitable.

The Stretcher Bar.—The simplest kind of support is the "stretcher bar." This consists essentially of a bar so constructed that it may be lengthened or shortened at pleasure, by means of a screw. It is fixed in position by screwing the ends into firm contact with the sides, or with the roof and the floor, of a heading. The machine is fixed to this bar by means of a clamp, which, when loosened, slides along the bar, and allows the drill to be placed in the required position, and to be directed at the required angle. The bar illustrated in Fig. 26, Plate V., is that which is used with the Darlington drill; in it, lightness and rigidity are combined in the highest possible degree by the adoption of the hollow section. The mode of setting the bar in a heading is shown in the drawing; the end claws are set against pieces of wood on the floor and the roof, and are tightened by turning the screw with a common bar.

The simple stretcher bar is frequently used in narrow drivings and in shafts of small diameter. But a more satisfactory support in drivings is afforded by a bar suitably mounted upon a carriage designed to run upon rails. The carriage consists simply of a trolly, to the fore part of which the bar is fixed usually by some kind of hinge-joint. It is obvious that the details of the construction of this support may be varied greatly, and numerous designs have been introduced and adopted. In Figs. 27 and 28, Plate VI., is shown a support of this character designed by J. Darlington. A single vertical bar is carried on the fore part of the trolly, and fixed, by the usual means, against the centre of the roof. This vertical bar carries an arm, which is capable of turning upon it, as upon a centre, and of sliding up and down it. This arm carries the drill. The central bar having been fixed in position, the arm is slid up to the highest position required, and fixed against the side of the heading. A row of holes are then bored from this arm. When these are completed, the arm is lowered the requisite distance, and another row of holes are bored. This is continued until all the holes are bored over one-half the face. The arm is then swung round, and fixed against the other side of the heading, and the holes are bored over that half the face in like manner. In this way, one-half the heading is kept clear to allow the operations of removing the dislodged rock to be carried on at the same time. If desired, two arms may be used. This arrangement gives undoubtedly great facilities for working the drill, and leaves the heading comparatively unencumbered.

In shaft sinking, the same support, slightly modified, is used without the trolly. The arrangement adopted in this case is shown in Fig. 29, Plate VII. The central bar is held firmly in its position by a cross stretcher bar set against the sides of the shaft. The arms are made to revolve upon this bar to allow the holes to be bored in the positions required. When all the holes have been bored, the support, with the machines, is hauled up, by means of a chain attached to the central bar, out of the way of the blast. With this support, the time of fixing, raising, and lowering is reduced to a minimum; while the facility with which the machines may be slid along and fixed to the arm, and the positions of the latter changed, allows the boring to be carried on rapidly.

For open work, as in quarrying, where the stretcher bar cannot be used, the tripod stand is adopted.

The Dubois-François Carriage.—The support commonly used in France and in Belgium consists of a kind of carriage carrying bars upon which the drills are set. This carriage is used in drivings of all kinds; but it is particularly suitable for tunnelling. It has been adopted, with but slight modification, in the St. Gothard tunnel, and in several other important works of the like character.

A modification of the carriage is shown in Figs. 30 and 31. Being designed for ordinary mining operations, it carries but two machines; but it will be readily perceived that, by increasing the number of vertical screws, the same support may be made to carry a larger number. It consists essentially of a vertical frame of flat bar iron *a b c d*, 8 feet in length, and 4 feet 9 inches in height above the rails, the hinder portion of which rests upon a cast-iron plate *e f g h*, carried upon two wheels; on this are fixed the two uprights *l*, *l′*, which, being bound to the upper part by a transverse bar *m m′*, form a framing to serve as a support to the two vertical screws *p′*, *q′*. The front framing is formed of two longitudinals *b c* and *b′ c′*, and the uprights *a*, *a′*, and the vertical screws *p*, *q*, which are connected to the upper part by the single piece *a d*. This framing is supported below upon a small trolly with four wheels, connected to the two longitudinals of the framing by a pivot bolt *n* of T form, the bar of the T being inserted into the elongated openings *o* cut through the middle of the curved portion of the longitudinals. The cast-iron plate behind, the use of which is only to give stability to the carriage, carries above it, by means of the two curved pieces *h*, *h′*, a wrought-iron plate V, upon which the small tools needed for repairs are kept. Two screws, *s*, *s′*, carried by lugs cast upon the back of the plate, serve, by turning them down upon the rails, to fix the carriage, the latter being slightly lifted by the screws.

Each machine is supported at two points. Behind, the point of support is given by a cast-iron bracket *t*, having a projecting eye which enters between the two cheeks formed at the back end of the machine by the continuations of the two longitudinals of the framing. A pin bolt, carried by the machine, allows the latter to be fixed to the bracket, while leaving sufficient freedom of motion to allow of its being directed at the required angle. This bracket, shown in plan in Fig. 33, is supported by a kind of nut, Fig. 32, having two handles whereby it may be easily turned. By raising or lowering this, the hinder support of the drill may be brought to the requisite height. To prevent it turning upon the screw, a pin is passed through the hole *o*, which pin forms a stop for the handles aforementioned. The rotation of the bracket itself is rendered impossible by the form of the vertical screw upon which it is set, as shown in Fig. 33. In front, the support is a fork, the shank of which slides along in the piece U, Figs. 30 and 31. This support, which is not screwed on the inside, rests upon a nut of the same form as that already described, and the same means are employed to prevent rotation as in the case of the hinder supports.

SECTION III.—APPLIANCES FOR FIRING BLASTING CHARGES.

In the foregoing sections, the machines and tools used in rock boring have been treated of. It now remains to describe those which are employed in firing the charges after they have been placed in the bore-holes. In this direction, too, great progress has been made in recent times. With the introduction of new explosive agents, arose the necessity for improved means of firing them. Attention being thus directed to the subject, its requirements were investigated and its conditions observed, the outcome being some important modifications of the old appliances and the introduction of others altogether new. Some of the improvements effected are scarcely less remarkable than the substitution of machine for hand boring.

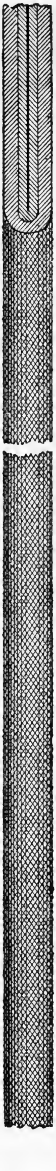
The means by which the charge of explosive matter placed in the bore-hole is fired constitute a very important part of the set of appliances used in blasting. The conditions which any such means must fulfil are: (1) that it shall fire the charge with certainty; (2) that it shall allow the person whose duty it is to explode the charge to be at a safe distance away when the explosion takes place; (3) that it shall be practically suitable, and applicable to all situations; and (4) that it shall be obtainable at a low cost. To fulfil the second and most essential of these conditions, the means must be either slow in operation, or capable of being acted upon at a distance. The only known means possessing the latter quality is electricity. The application of electricity to this purpose is of recent date, and in consequence of the great advantages which it offers, its use is rapidly extending. The other means in common use are those which are slow in operation, and which allow thereby sufficient time to elapse between their ignition and the explosion of the charge for a person to retire to a safe distance. These means consist generally of a train of gunpowder so placed that the ignition of the particles must necessarily be gradual and slow. The old, and in some parts still employed, mode of constructing this train was as follows: An iron rod of small diameter and terminating in a point, called a "pricker," was inserted into the charge and left in the bore-hole while the tamping was being rammed down. When this operation was completed, the pricker was withdrawn, leaving a hole through the tamping down to the charge. Into this hole, a straw, rush, quill, or some other like hollow substance filled with gunpowder, was inserted. A piece of slow-match was then attached to the upper end of this train, and lighted.

The combustion of the powder confined in the straw fired the charge, the time allowed by the slow burning of the match being sufficient to enable

FIG. 28.

the man who ignited it to retire to a place of safety. This method of forming the train does not, however, satisfy all the conditions mentioned above. It is not readily applicable to all situations. Moreover, the use of the iron pricker may be a source of danger; the friction of this instrument against silicious substances in the sides of the bore-hole or in the tamping has in some instances occasioned accidental explosions. This danger is, however, very greatly lessened by the employment of copper or phosphor-bronze instead of iron for the prickers. But the method is defective in some other respects. With many kinds of tamping, there is a difficulty in keeping the hole open after the pricker is withdrawn till the straw can be inserted. When the holes are inclined upwards, besides this difficulty, another is occasioned by the liability of the powder constituting the train to run out on being ignited. And in wet situations, special provision has to be made to protect the trains. Moreover, the manufacture of these trains by the workmen is always a source of danger. Many of these defects in the system may, however, be removed by the employment of properly constructed trains. One of these trains or "squibs" is shown full size in Fig. 28.

FIG. 29.



Safety Fuse.—Many of the defects pertaining to the system were removed by the introduction of the fuse invented by W. Bickford, and known as "safety fuse." The merits of this fuse, which is shown full size in Fig. 29, are such as to render it one of the most perfect of the slow-action means that have yet been devised. The train of gunpowder is retained in this fuse, but the details of its arrangement are changed so as to fairly satisfy the conditions previously laid down as necessary. It consists of a flexible cord composed of a central core of fine gunpowder, surrounded by hempen yarns twisted up into a tube, and called the countering. An outer casing is made of different materials, according to the circumstances under which it is intended to be used. A central touch thread, or in some cases two threads, passes through the core of gunpowder. This fuse, which in external appearance resembles a piece of plain cord, is tolerably certain in its action; it may be used with equal facility in holes bored in any direction; it is capable of resisting considerable pressure without injury; it may be used without special means of protection in wet ground; and it may be transported from place to place without risk of damage.

In the safety fuse, the conditions of slow burning are fully satisfied, and certainty is in some measure provided for by the touch thread through the centre of the core. As the combustion of the core leaves, in the small space occupied by it, a carbonaceous residue, there is little or no passage left through the tamping by which the gases of the exploding charge may escape, as in the case of the squibs. Hence results an economy of force. Another advantage offered by the safety fuse is, that it may be made to carry the fire into the centre of the bursting charge if it be desired to produce rapid ignition. This fuse can be also very conveniently used for firing charges of compounds other than gunpowder, by fixing a detonating charge at the end of it, and dropping the latter into the charge of the compound. This means is usually adopted in firing the nitro-glycerine compounds, the detonating charge in such cases being generally contained within a metallic cap. In using this fuse, a sufficient length is cut off to reach from the charge to a distance of about an inch, or farther if necessary, beyond the mouth of the hole. One end is then untwisted to a height of about a quarter of an inch, and placed to that depth in the charge. The fuse being placed against the side of the bore-hole with the other end projecting beyond it, the tamping is put in, and the projecting end of the fuse slightly untwisted. The match may then be applied directly to this part. The rate of burning is about two and a half feet a minute.

Safety fuse is sold in coils of 24 feet in length. The price varies according to the quality, and the degree of protection afforded to the train.

Electric Fuses.—The employment of electricity to fire the charge in blasting rock offers numerous and great advantages. The most important, perhaps, is the greatly increased effect of the explosions when the charges are fired simultaneously. But another advantage, of no small moment, lies in the security from accident which this means of firing gives. When electricity is used, not only may the charge be fired at the moment desired, after the workmen have retired to a place of safety, but the danger due to a misfire is altogether avoided. Further, the facility afforded by electricity for firing charges under water is a feature in this agent of very great practical importance. It would therefore seem, when all these advantages are taken into account, that electricity is destined to become of general application to blasting purposes in this country, as it is already in Germany and in America.

An electric fuse consists of a charge of an explosive compound suitably placed in the circuit of an electric current, which compound is of a character to be acted upon by the current in a manner and in a degree sufficient to produce explosion. The mode in which the current is made to act depends upon the nature of the source of the electricity. That which is generated by a machine is of high tension, but small in quantity; while that which is generated by a battery is, on the contrary, of low tension, but is large in quantity. Electricity of high tension is capable of leaping across a narrow break in the circuit, and advantage is taken of this property to place in the break an explosive compound sufficiently sensitive to be decomposed by the passage of the current. The electricity generated in a battery, though incapable of leaping across a break in the circuit, is in sufficient quantity to develop a high degree of heat. Advantage is taken of this property to fire an explosive compound by reducing the sectional area of the wire composing a portion of the circuit at a certain point, and surrounding this wire with the compound. It is obvious that any explosive compound may be fired in this way; but for the purpose of increasing the efficiency of the battery, preference is given to those compounds which ignite at a low temperature. Hence it will be observed that there are two kinds of electric fuses, namely, those which may be fired by means of a machine, and which are called "tension" fuses, and those which require a battery, and which are known as "quantity" fuses.

In the tension, or machine fuses, the circuit is interrupted within the fuse case, and the priming, as before remarked, is interposed in the break; the current, in leaping across the interval, passes through the priming. In the quantity or battery fuses, the reduction of the sectional area is effected by severing the conducting wire within the fuse case, and again joining the severed ends of the wire by soldering to them a short piece of very fine wire. Platinum wire, on account of its high resistance and low specific heat, is usually employed for this purpose. The priming composition is placed around this fine wire, which is heated to redness by the current as soon as the circuit is closed.

The advantages of high tension lie chiefly in the convenient form and ready action of the machines employed to excite the electricity. Being of small dimensions and weight, simple in construction, and not liable to get quickly out of order, these sources of electricity are particularly suitable for use in mining operations, especially when these operations are entrusted, as they usually are, to men of no scientific knowledge.

Another advantage of high tension is the small effect of line resistance upon the current, a consequence of which is that mines may be fired at long distances from the machine, and through iron wire of very small section. A disadvantage of high tension is the necessity for a perfect insulation of the wires.

When electricity of low tension is employed, the insulation of the wires needs not to be perfect, so that leakages arising from injury to the coating of the wire are not of great importance. In many cases, bare wires may be used. Other advantages of low tension are the ability to test the fuse at any moment by means of a weak current, and an almost absolute certainty of action. For this reason, it is usually preferred for torpedoes and important submarine work. On the other hand, the copper wires used must be of comparatively large section, and the influence of line resistance is so considerable that only a small number of shots can be fired simultaneously when the distance is great.

FIG. 30.

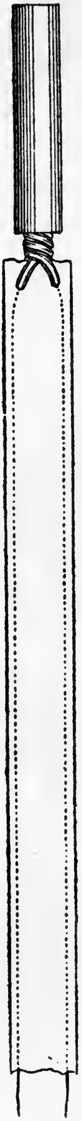
In Fig. 30 is shown an external view of an electric tension fuse. It consists of a metal cap containing a detonating composition, upon the top of which is placed the priming to be ignited by the electric spark. The ends of two insulated wires project into this priming, which is fired by the passage of the spark from one of these wires to the other. The insulated wires are sufficiently long to reach a few inches beyond the bore-hole.

Sometimes the fuse is attached to the end of a stick, and the wires are affixed to the latter in the manner shown in

Fig. 31. The rigidity of the stick allows the fuse to be readily pushed into the bore-hole. When the ground is not very wet, bare wires are, for cheapness, used, and the stick is in that case covered with oiled paper, or some other substance capable of resisting moisture. These "blasting sticks," as they are called, are extensively used in Germany. When heavy tamping is employed, the stick is not suitable, by reason of the space which it occupies in the bore-hole.

Fig. 31.

Fig. 32.



A mode of insulating the wires, less expensive than the guttapercha shown in Fig. 30, is illustrated in Fig. 32. In this case, the wires are cemented between strips of paper, and the whole is dipped into some resinous substance to protect it from water. These "ribbon" wires may be used in ground that is not very wet. They occupy little or no space in the bore-hole, and therefore are suitable for use with tamping.

To connect the fuses with the machine or the battery, two sets of wires are required when a single shot is fired, and three sets may be needed when two or more shots are fired simultaneously. Of these several sets of wires, the first consists of those which are attached to the fuses, and which, by reason of their being placed in the shot-hole, are called the "shot-hole wires." Two shot-hole wires must be attached to each fuse, and they must be of such a length that, when the fuse has been placed in its proper position in the charge, the ends may project a few inches from the hole. These wires must also be "insulated," that is, covered with a substance capable of preventing the escape of electricity.

The second set of wires consists of those which are employed to connect the charges one with another, and which, for this reason, are called "connecting wires." In connecting the charges in single circuit, the end of one of the shot-hole wires of the first charge is left free, and the other wire is connected, by means of a piece of this connecting wire, to one of the shot-hole wires in the second hole; the other wire in this second hole is then connected, in the same manner, to one of the wires in the third hole; and so on till the last hole is reached, one shot-hole wire of which is left free, as in the first. Whenever the connecting wires can be kept from touching the rock, and also from coming into contact one with another—and in most cases this may be done—bare wire may be used, the cost of which is very little.

But when this condition cannot be complied with, and, of course, when blasting in water, the connecting wires, like the shot-hole wires, must be insulated. When guttapercha shot-hole wires are used, it is best to have them sufficiently long to allow the ends projecting from one hole to reach those projecting from the next hole. This renders connecting wire unnecessary, and moreover saves one joint for each shot.

Cables.—The third set of wires required consists of those used to connect the charges with the machine or the battery. These wires, which are called the "cables," consist each of three or more strands of copper wire well insulated with guttapercha, or better, indiarubber, the coating of these materials being protected from injury by a sheathing of tape or of galvanized iron wire underlaid with hemp. Two cables are needed to complete the circuit; the one which is attached to the positive pole of the machine, that is, the pole through which the electric current passes out, is distinguished as the "leading cable," and the other, which is attached to the negative pole, that is, the pole through which the current returns to the machine, is described as the return cable. Sometimes both the leading and the return cables are contained within one covering. When a cable having a metallic sheathing is used, the sheathing may be made to serve as a return cable, care being taken to make good metallic contact with the wires that connect the sheathing to the fuses and to the terminal of the machine. The best kind of unprotected cable consists of a three-strand tinned copper wire, each 0·035 inch in diameter, insulated with three layers of indiarubber to 0·22 inch diameter, and taped with indiarubber-saturated cotton to 0·24 inch diameter, as shown in Fig. 33. The best protected cable consists of a similar strand of copper wire, covered with guttapercha and tarred jute, and sheathed with fifteen galvanized iron wires of 0·08 inch diameter each, to a total diameter of 0·48 inch, as shown in Fig. 34.

Fig. 33.

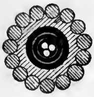


Fig. 34.

Detonators.—The new explosives of the nitro-cotton and nitro-glycerine class cannot be effectively fired by means of safety or other fuse alone. To bring about their instantaneous decomposition, it is necessary to produce in their midst the explosion of some other substance. The force of this initial explosion causes the charge of gun-cotton, or dynamite, as the case may be, to detonate. It has been found that the explosion of the fulminate of mercury brings about this result most effectively and with the greatest certainty; and this substance is therefore generally used for the purpose. The charge of fulminate is contained in a copper capsule about a quarter of an inch in diameter, and from 1 inch to 1¼ inch in length. These caps, with their charge of fulminate, which are now well known to users of the nitro-compounds, are called "detonators." It is of the highest importance that these detonators should contain a sufficiently strong charge to produce detonation, for if too weak, not only is the whole force of the explosive not developed, but a large quantity of noxious gas is generated. Gun-cotton requires a much stronger charge of fulminate than dynamite.

In the electric fuses illustrated, the metal case shown is the detonator, the fuse being placed inside above the fulminate. When safety fuse is used, the end is cut off clean and inserted into the cap, which is then pressed tightly upon the fuse by means of a pair of nippers, as shown in Fig. 35. When water tamping is used, and when, with ordinary tamping, the hole is very wet, a little white-lead or grease must be put round the edge of the cap as a protection. The electric fuses are always made waterproof; consequently, they are ready for use under all circumstances. When the safety fuse burns down into the cap, or when, in the other case, the priming of the electric fuse is fired, the fulminate explodes and causes the detonation of the charge in which it is placed.

FIG. 35.

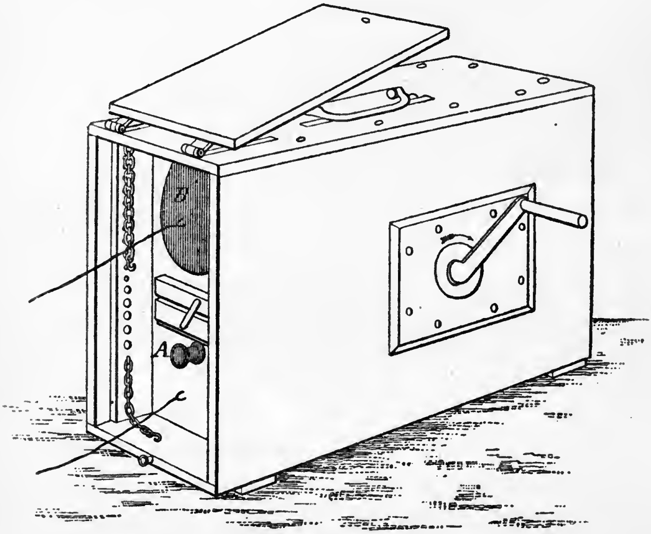
Firing Machines and Batteries.—The electrical machines used for firing tension fuses are of two kinds. In one kind, the electricity is excited by friction, and stored in a condenser to be afterwards discharged by suitable means provided for the purpose. In the other kind, the electricity is excited by the motion of an armature before the poles of a magnet. The former kind are called "frictional electric" exploders; the latter kind are known as "magneto-electric" exploders. When a magneto-electric machine contains an electro-magnet instead of a permanent magnet, it is described as a "dynamo-electric exploder.

Frictional machines act very well as exploders so long as they are kept in a proper state. But as they are injuriously affected by a moist atmosphere, and weaken rapidly with use by reason of the wearing away of the rubbers, it is necessary to take care that they be in good electrical condition before using them for firing. Unless this care be taken, the quantity of electricity excited by a given number of revolutions of the plate will be very variable, and vexatious failures will ensue. If, however, the proper precautions be observed, very certain and satisfactory results may be obtained. In Germany and in America, frictional exploders are generally used.

Magneto-electric machines possess the very valuable quality of constancy. They are unaffected, in any appreciable degree, by atmospheric changes, and they are not subject to wear. These qualities are of inestimable worth in an exploder used for ordinary blasting operations. Moreover, as they give electricity of a lower tension than the frictional machines, defects of insulation are less important. Of these machines, only the dynamo variety are suitable for industrial blasting. It is of primary importance that an exploder should possess great power. The mistake of using weak machines has done more than anything else to hinder the adoption of electrical firing in this country.

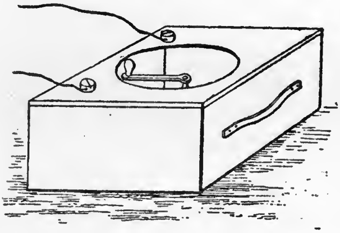
The machine most used in Germany is Bornhardt's frictional exploder, shown in Fig. 36. This machine is contained in a wooden case 20 inches in length, 7 inches in breadth, and 14 inches in depth, outside measurement. The weight is about 20 lb.

Fig. 36.



To fire the charges by means of this exploder, the leading wire is attached to the upper terminal B, and the return to the lower terminal C, the other ends of these wires being connected to the fuses. The handle is then turned briskly from fifteen to thirty times, according to the number of the fuses and the state of the machine, to excite the electricity. The knob A is then pressed suddenly in, and the discharge takes place. To ascertain the condition of the machine, a scale of fifteen brass-headed nails is provided on the outside, which scale may be put in communication with the poles B and C by means of brass chains, as shown in the drawing. If after twelve or fourteen turns, the spark leaps the scale when the knob is pushed in, the machine is in a sufficiently good working condition. To give security to the men engaged, the handle is designed to be taken off when the machine is not in actual use; and the end of the machine into which the cable wires are led is made to close with a lid and lock, the key of which should be always in the possession of the man in charge of the firing operations.

Fig. 37.

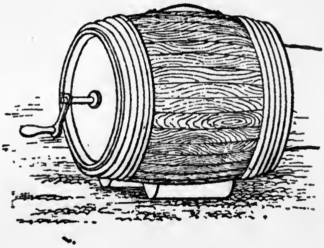


In America, there are two frictional exploders in common use. One, shown in Fig. 37, is the invention of H. Julian Smith. The apparatus is enclosed in a wooden case about 1 foot square and 6 inches in depth.

The handle is on the top of the case, and is turned horizontally. This handle is removable, as in Bornhardt's machine. The cable wires having been attached to the terminals, the handle is turned forward a certain number of times to excite the electricity, and then turned a quarter of a revolution backward to discharge the condenser and to fire the blast. By this device, the necessity for a second aperture of communication with the inside is avoided, an important point in frictional machines, which are so readily affected by moisture. The aperture through which the axis of the plate passes, upon which axis the handle is fixed, is tightly closed by a stuffing-box. A leathern strap on one end of the case allows the machine to be easily carried. The weight of this exploder is under 10 lb.

The other exploder used is that designed by G. Mowbray. This machine, which is shown in Fig. 38, is contained in a wooden barrel-shaped case, and is known as the "powder-keg" exploder, the form and dimensions of the case being those of a powder-keg. The action is similar to that of the machine last described. The cable wires having been attached to the terminals at one end of the keg, the handle at the other end is turned forward to excite the

Fig. 38.

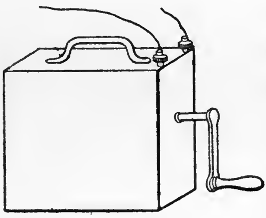


electricity, and the condenser is discharged by making a quarter turn backward, as in Smith's machine. The handle is in this case also removable. The weight of the powder-keg exploder is about 26 lb.

Both of these machines are very extensively used, and good results are obtained from them. They stand well in a damp atmosphere, and do not quickly get out of order from the wearing of the rubbers. They are also, especially the former, very easily portable.

The machine commonly used in England is the dynamo-electric exploder of the Messrs. Siemens. This machine, which is the best of its kind yet introduced for blasting purposes, is not more than half the size of Bornhardt's frictional exploder; but it greatly exceeds the latter in weight, that of Siemens' being about 55 lb. The apparatus, which is contained within the casing shown in Fig. 39, consists of an ordinary Siemens' armature, which is made, by turning the handle, to revolve between the poles of an electro-magnet. The coils of the electro-magnet are in circuit with the wire of the armature; the residual magnetism of the electro-magnet cores excites, at first, weak currents; these pass into the coils, thereby increasing the magnetism

Fig. 39.



of the cores, and inducing still stronger currents in the armature wire, to the limit of magnetic saturation of the iron cores of the electro-magnets. By the automatic action of the machine, this powerful current is, at every second turn of the handle, sent into the cables leading to the fuses.

To fire this machine, the handle is turned gently till a click is heard from the inside, indicating that the handle is in the right position to start from. The cable wires are then attached to the terminals, and the handle is turned quickly, but steadily. At the completion of the second revolution, the current is sent off into line, as it is termed, that is, the current passes out through the cables and the fuses. As in the case of the frictional machines, the handle is, for safety, made removable. This exploder is practically unaffected by moisture, and it is not liable to get out of order from wear.

Induction coils have been used to fire tension fuses; but it is surprising that they have not been more extensively applied to that purpose. A coil designed for the work required of it is a very effective instrument. If constructed to give a spark not exceeding three inches in length, with comparatively thick wire for quantity, it makes a very powerful exploder. An objection to its use is the necessity for a battery. But a few bichromate of potash cells, provided with spiral springs to hold the zincs out of the liquid, and designed to be set in action by simply pressing down the zincs, give but little trouble, so that the objection is not a serious one. The writer has used an induction exploder in ordinary mining operations without experiencing any difficulty or inconvenience. It is cheap, easily portable, and constant in its action.

Batteries are used to fire what are known as "quantity" or "low tension" fuses. Any cells may be applied to this purpose; but they are not all equally suitable. A firing battery should require but little attention, and should remain in working order for a long time. These conditions are satisfactorily fulfilled by only two cells, namely, the Léclanché and the Bichromate of Potash. The latter is the more powerful, and generally the more suitable. The Léclanché is much used in this country for firing purposes, under the form known as the "Silvertown Firing Battery." This battery consists of a rectangular teak box, containing ten cells. Two, or more, of these may be joined up together when great power is required. In France, the battery used generally for firing is the Bichromate. This battery is much more powerful than the Léclanché, and as no action goes on when the zincs are lifted out of the liquid, it is equally durable. It is moreover much cheaper. At the suggestion of the writer, Mr. Apps, of the Strand, London, has constructed a bichromate firing battery of very great power. It is contained in a box of smaller dimension than the 10-cell Silvertown. The firing is effected by simply lowering the zincs, which rise again automatically out of the liquid, so that there is no danger of the battery exhausting itself by continuous action in case of neglect. Externally, this battery, like the Silvertown, appears a simple rectangular box, so that no illustration is needed. With either of these, the usual objections urged against the employment of batteries, on the ground of the trouble involved in keeping them in order, and their liability to be injured by ignorant or careless handling, do not apply, or at least apply in only a very unimportant degree.

To guard against misfires, the machine or the battery used should be constructed to give a very powerful current. If this precaution be observed, and the number of fuses in circuit be limited to one-half that which the machine is capable of firing with a fair degree of certainty, perfectly satisfactory results may be obtained. The employment of weak machines and batteries leads inevitably to failure. In the minds of those who have hitherto tried electrical blasting in this country, there seems to be no notion of any relation existing between the work to be done and the force employed to do it. The electrical exploder is regarded as a sort of magic box that needs only to be set in action to produce any required result. Whenever failure ensues, the cause is unhesitatingly attributed to the fuses.

CHAPTER II.

EXPLOSIVE AGENTS USED IN BLASTING ROCKS.

SECTION I.—PHENOMENA ACCOMPANYING AN EXPLOSION.

Nature of an Explosion.—The combination of oxygen with other substances for which it has affinity is called generally "oxidation." The result of this combination is a new substance, and the process of change is accompanied by the liberation of heat. The quantity of heat set free when two substances combine chemically is constant, that is, it is the same under all conditions. If the change takes place within a short space of time, the heat becomes sensible; but if the change proceeds very slowly, the heat cannot be felt. The same *quantity*, however, is liberated in both cases. Thus, though the quantity of heat set free by a chemical combination is under all conditions the same, the degree or *intensity* of the heat is determined by the rapidity with which the change is effected.

When oxidation is sufficiently rapid to cause a sensible degree of heat, the process is described as "combustion." The oxidation of a lump of coke in the furnace, for example, is effected within a short space of time, and, as the quantity of heat liberated by the oxidation of that weight of carbon is great, a high degree results. And it is well known and obvious that as combustion is quickened, or, in other words, as the time of change is shortened, the intensity of the heat is proportionally increased. So in the case of common illuminating gas, the oxidation of the hydrogen is rapidly effected, and, consequently, a high degree of heat ensues.

When oxidation takes place within a space of time so short as to be inappreciable to the senses, the process is described as "explosion." The combustion of a charge of gunpowder, for example, proceeds with such rapidity that no interval can be perceived to intervene between the commencement and the termination of the process. Oxidation is in this case, therefore, correctly described as an explosion; but the combustion of a train of gunpowder, or of a piece of quick-match, though exceedingly rapid, yet, as it extends over an appreciable space of time, is not to be so described. By analogy, the sudden change of state which takes place when water is "flashed" into steam, is called an explosion. It may be remarked here that the application of this expression to the bursting of a steam boiler is an abuse of language; as well may we speak of an "explosion" of rock.

From a consideration of the facts stated in the foregoing paragraphs, it will be observed that oxidation by explosion gives the maximum intensity of heat.

Measure of Heat, and specific Heat.—It is known that if a certain quantity of heat will raise the temperature of a body one degree, twice that quantity will raise its temperature two degrees, three times the quantity, three degrees, and so on. Thus we may obtain a measure of heat by which to determine, either the temperature to which a given quantity of heat is capable of raising a given body, or the quantity of heat which is contained in a given body at a given temperature. The quantity of heat requisite to produce a change of one degree in temperature is different for different bodies, but is practically constant for the same body, and this quantity is called the "specific heat" of the body. The standard which has been adopted whereby to measure the specific heat of bodies is that of water, the unit being the quantity of heat required to raise the temperature of 1 lb. of water through 1° Fahr., say from 32° to 33°. The quantity of heat required to produce this change of temperature in 1 lb. of water is called the "unit of heat," or the "thermal unit." Having determined the specific heat of water, that of air may in like manner be ascertained, and expressed in terms of the former. It has been proved by experiments that if air be heated at constant pressure through 1° Fahr., the quantity of heat absorbed is 0·2375 thermal units, whatever the pressure or the temperature of the air may be. Similarly it has been shown that the specific heat of air at constant volume is, in thermal units, 0·1687; that is, if the air be confined so that no expansion can take place, 0·1687 of a thermal unit will be required to increase its temperature one degree.

Heat liberated by an Explosion.—In the oxidation of carbon, one atom of oxygen may enter into combination with one atom of that substance; the resulting body is a gas known as "carbonic oxide." As the weight of carbon is to that of oxygen as 12 is to 16, 1 lb. of the former substance will require for its oxidation $1\frac{1}{3}$ lb. of the latter; and since the two enter into combination, the product, carbonic oxide, will weigh $1 + 1\frac{1}{3} = 2\frac{1}{3}$ lb. The combining of one atom of oxygen with one of carbon throughout this quantity, that is, $1\frac{1}{3}$ lb. of oxygen, with 1 lb. of carbon, generates 10,100 units of heat. Of this quantity, 5700 units are absorbed in changing the carbon from the solid into the gaseous state, and 4400 are set free. The quantity of heat liberated, namely, the 4400 units, will be expended in raising the temperature of the gas from 32° Fahr., which we will assume to be that of the carbon and the oxygen previous to combustion, to a much higher degree, the value of which may be easily determined. The 4400 units would raise 1 lb. of water from 32° to $32 + 4400 = 4432°$; and as the specific heat of carbonic oxide is 0·17 when there is no increase of volume, the same quantity of heat will raise 1 lb. of that gas from 32° to $32 + \frac{4400}{0 \cdot 17} = 25{,}914°$. But in the case under consideration, we have $2\frac{1}{3}$ lb. of the gas, the resulting temperature of which will be $\frac{25{,}914}{2\frac{1}{3}} = 9718°$.

In the oxidation of carbonic oxide, one atom of oxygen combines with one atom of the gaseous carbon; the resulting body is a gas known as "carbonic acid." Since $2\frac{1}{3}$ lb. of carbonic oxide contains 1 lb. of carbon, that quantity of the oxide will require $1\frac{1}{3}$ lb. of oxygen to convert it into the acid, that is, to completely oxidize the original pound of solid carbon. By this combination, 10,100 units of heat are generated, as already stated, and since the carbon is now in the gaseous state, the whole of that quantity will be set free. Hence the temperature of the resulting $3\frac{2}{3}$ lb. of carbonic acid will be

$$32 + \frac{4400 + 10{,}100}{0 \cdot 17 \times 3 \cdot 667} = 23{,}516°.$$

It will be seen from the foregoing considerations that if 1 lb. of pure carbon be burned in $2\frac{2}{3}$ lb. of pure oxygen, $3\frac{2}{3}$ lb. of carbonic acid is produced, and 14,500 units of heat are liberated; and further, that if the gas be confined within the space occupied by the carbon and the oxygen previously to their combination, the temperature of the product may reach 23,516° Fahr.

In the oxidation of hydrogen, one atom of oxygen combines with two atoms of the former substance; the resulting body is water. As the weight of hydrogen is to that of oxygen as 1 is to 16, 1 lb. of the former gas will require for its oxidation 8 lb. of the latter; and since the two substances enter into combination, the product, water, will weigh $1 + 8 = 9$ lb. By this union, 62,032 units of heat are generated. Of this quantity, 8694 are absorbed in converting the water into steam, and 53,338 are set free. The specific heat of steam at constant volume being 0·37, the temperature of the product of combustion, estimated as before, will be

$$32 + \frac{53{,}338}{0 \cdot 37 \times 9} = 16{,}049^\circ.$$

Hence it will be observed that if 1 lb. of hydrogen be burned in 8 lb. of oxygen, 9 lb. of steam will be produced, and 53,338 units of heat will be liberated; and further, that the temperature of the product may reach 16,049°.

Gases generated by an Explosion.—It was shown in the preceding paragraph that in the combustion of carbon, one atom of oxygen may unite with one atom of carbon to form carbonic oxide, or two atoms of oxygen may unite with one atom of carbon to form carbonic acid. When the combination takes place according to the former proportions, the reaction is described as "imperfect combustion," because the carbon is not fully oxidized; but when the combination is effected in the latter proportions, the combustion is said to be "perfect," because no more oxygen can be taken up. The products of combustion are in both cases gaseous. Carbonic oxide, the product of imperfect combustion, is an extremely poisonous gas; it is this gas which is so noisome in close headings, and in all ill-ventilated places, after a blast has been fired. A cubic foot of carbonic oxide, the specific gravity of which is 0·975, weighs, at the mean atmospheric pressure, 0·075 lb., so that 1 lb. will occupy a space of 13·5 cubic feet. Thus 1 lb. of carbon imperfectly oxidized will give $2\frac{1}{3}$ lb. of carbonic oxide, which, at the mean atmospheric pressure of 30 inches and the mean temperature of 62° Fahr., will occupy a space of $13 \cdot 5 \times 2\frac{1}{3} = 31 \cdot 5$ cubic feet. The product of perfect combustion, carbonic acid, is a far less noxious gas than the oxide, and it is much more easily expelled from confined places, because water possesses the property of absorbing large quantities of it. In an ill-ventilated but wet heading, the gas from a blast is soon taken up. Carbonic acid is a comparatively heavy gas, its specific gravity relatively to that of common air being 1·524. Hence a cubic foot at the ordinary pressure and temperature will weigh 0·116 lb., and 1 lb. of the gas under the same conditions will occupy a space of 8·6 cubic feet. Thus if 1 lb. of carbon be completely oxidized, there will result $3\frac{2}{3}$ lb. of carbonic acid, which will fill a space of $8·6 \times 3\frac{2}{3} = 31·5$ cubic feet. It will be observed that, though an additional pound of oxygen has been taken up during this reaction, the product occupies the same volume as the oxide. In complete combustion, therefore, a contraction takes place.

In the oxidation of hydrogen, as already pointed out, one atom of oxygen combines with two atoms of the former substance to form water. In this case, the product is liquid. But the heat generated by the combustion converts the water into steam, so that we have to deal with this product also in the gaseous state, in all considerations relating to the effects of an explosion. A cubic foot of steam, at atmospheric pressure and a temperature of 212° Fahr., weighs 0·047 lb.; 1 lb. of steam under these conditions will, therefore, occupy a space of 21·14 cubic feet. Thus the combustion of 1 lb. of hydrogen will produce 9 lb. of steam, which, under the conditions mentioned, will fill a space of $21·14 \times 9 = 190·26$ cubic feet.

Usually in an explosion a large quantity of nitrogen gas is liberated. This gas, which is not in itself noxious, has a specific gravity of 0·971, so that practically a cubic foot will weigh 0·075 lb., and 1 lb. will occupy a space of 13·5 cubic feet, which are the weight and the volume of carbonic oxide.

Other gases are often formed as products of combustion; but the foregoing are the chief, viewed as the results of an explosion, since upon these the force developed almost wholly depends.

Force developed by an Explosion.—A consideration of the facts enunciated in the foregoing paragraphs will show to what the tremendous energy developed by an explosion is due. It was pointed out that the combustion of 1 lb. of carbon gives rise to 31·5 cubic feet of gas. If this volume of gas be compressed within the space of 1 cubic foot it will obviously have a tension of 31·5 atmospheres; that is, it will exert upon the walls of the containing vessel a pressure of 472 lb. to the square inch. If the same volume be compressed into a space one-eighth of a cubic foot in extent, say a vessel of cubical form and 6 inches side, the tension will be $31 \cdot 5 \times 8 = 252$ atmospheres, and the pressure $472 \times 8 = 3776$ lb. to the square inch. Assuming now the oxygen to exist in the solid state, and the two bodies carbon and oxygen to occupy together a space of one-eighth of a cubic foot, the combustion of the carbon will develop upon the walls of an unyielding containing vessel of that capacity a pressure of 252 atmospheres. Also the combustion of 1 lb. of hydrogen gives rise, as already remarked, to 190·26 cubic feet of steam; and if combustion take place under similar conditions with respect to space, the pressure exerted upon the containing vessel will be 22,830 lb., or nearly 10·5 tons, to the square inch, the tension being $190 \cdot 26 \times 8 = 1522$ atmospheres.

The force thus developed is due wholly to the volume of the gas generated, and by no means represents the total amount developed by the explosion. The volume of the gases evolved by an explosion is estimated for a temperature of 62°; but it was shown in a former paragraph that the temperature of the products of combustion at the moment of their generation is far above this. Now it is a well-known law of thermo-dynamics that, the volume remaining the same, the pressure of a gas will vary directly as the temperature; that is, when the temperature is doubled, the pressure is also doubled. By temperature is understood the number of degrees measured by Fahrenheit's scale on a perfect gas thermometer, from a zero 461°·2 below the zero of Fahrenheit's scale, that is, 493°·2 below the freezing point of water. Thus the temperature of 62° for which the volume has been estimated is equal to $461 \cdot 2 + 62 = 523° \cdot 2$ absolute.

It was shown that the temperature of the product of combustion when carbon is burned to carbonic oxide is 9718° Fahr., which is equivalent to 10179°·2 absolute. Hence it will be observed that the temperature has been increased $\frac{10179° \cdot 2}{523° \cdot 2} = 19 \cdot 45$ times. According to the law above enunciated, therefore, the pressure will be increased in a like ratio, that is, it will be, for the volume and the space already given, 3776 × 19·45 = 73,443 lb. = 32·8 tons to the square inch.

When carbon is burned to carbonic acid, the temperature of the product was shown to be 23,516° Fahr., which is equivalent to 23977·2 absolute. In this case, it will be observed that the temperature has been increased $\frac{23977 \cdot 2}{523 \cdot 2} = 45 \cdot 83$ times. Hence the resulting pressure will be 3776 × 45·83 = 173,154 lb. = 77·3 tons to the square inch. It will be seen from these pressures that when combustion is complete, the force developed is 2·36 greater than when combustion is incomplete; and also that the increase of force is due to the larger quantity of heat liberated, since the volume of the gases is the same in both cases. If we suppose the carbon burned to carbonic oxide in the presence of a sufficient quantity of oxygen to make carbonic acid, we shall have 31·5 cubic feet of the oxide + 15·7 cubic feet of free oxygen, or a total volume of 42·7 cubic feet of gases. If this volume be compressed within the space of one-eighth of a cubic foot, it will have a tension of 42·7 × 8 = 341·6 atmospheres, and will exert upon the walls of the containing vessel a pressure of 5124 lb. to the square inch. The temperature of the gases will be $32 + \frac{4400}{0 \cdot 190 \times 3 \cdot 667} = 6347°$

Fahr. = 6808°·2 absolute, the mean specific heat of the gases being 0·190; whence it will be seen that the temperature has been increased $\frac{6808 \cdot 2}{523 \cdot 2} = 13 \cdot 01$ times. According to the law of thermo-dynamics, therefore, the pressure under the foregoing conditions will be 5124 × 13·01 = 66,663 lb. = 29·8 tons to square inch. So that, under the conditions assumed in this case, the pressures developed by incomplete and by complete combustion are as 29·8 to 77·3, or as 1 to 2·59.

Similarly, when hydrogen is burned to water, the temperature of the product will be, as shown in a former paragraph, 16,049 Fahr. = 16510·2 absolute; and the pressure will be $22{,}830 \times \frac{16510 \cdot 2}{523 \cdot 2} =$ 720,286 lb. = 321·1 tons to the square inch.

It will be observed, from a consideration of the foregoing facts, that a very large proportion of the force developed by an explosion is due to the heat liberated by the chemical reactions which take place. And hence it will plainly appear that, in the practical application of explosive agents to rock blasting, care should be taken to avoid a loss of the heat upon which the effects of the explosion manifestly so largely depend.

SECTION II.—NATURE OF EXPLOSIVE AGENTS.

Mechanical Mixtures.—In the preceding section, it was shown that an explosion is simply the rapid oxidation of carbon and hydrogen. To form an explosive agent, the problem is, how to bring together in a convenient form the combustible, carbon or hydrogen, and the oxygen required to oxidize it. Carbon may be obtained pure, or nearly pure, in the solid form. As wood charcoal, for example, that substance may be readily procured in any needful abundance; but pure oxygen does not exist in that state, and it is hardly necessary to point out that only the solid form is available in the composition of an explosive agent. In nature, however, oxygen exists in the solid state in very great abundance in combination with other substances. Silica, for example, which is the chief rock constituent, is a compound of silicon and oxygen, and the common ores of iron are made up chiefly of that metal and oxygen. The elementary constituents of cellulose, or wood fibre, are carbon, hydrogen, and oxygen; and the body known as saltpetre, or nitrate of potash, is compounded of potassium, nitrogen, and oxygen. But though oxygen is thus found in combination with many different substances, it has not the same affinity for all. When it is combined with a substance for which its affinity is strong, as in the silica and the iron oxide, it cannot be separated from that substance without difficulty; but if the affinity be weak, dissociation may be more easily effected. The former combination is said to be "stable," and the latter is, in contradistinction, described as "unstable." It will be evident on reflection that only those compounds in which the oxygen exists in unstable combination can be made use of as a constituent part of an explosive agent, since it is necessary that, when required, the oxygen shall be readily given up. Moreover, it will also appear that when one of these unstable oxygen compounds and carbon are brought together the mixture will constitute an explosive agent, since the oxygen which is liberated by the dissociation of the unstable compound will be taken up by the carbon for which it has a stronger affinity. Saltpetre is one of those compounds, and a mixture of this body with charcoal constitutes gunpowder. The means employed to dissociate the elements of saltpetre is heat. It is obvious that other compounds of oxygen might be substituted for the saltpetre, but this body being easily procurable is always employed. The chlorate of potash, for example, is less stable than the nitrate, and therefore an explosive mixture containing the former substance will be more violent than another containing the latter. For the violence of an explosion is in a great measure determined by the readiness with which the oxygen is given up to the combustible. But the chlorate is much more costly than the nitrate. As, however, the force developed is greater, the extra cost would perhaps be compensated by the increased effect of the explosion. But the instability of the chlorate is such that friction or a moderately light blow will produce explosion in a mixture containing that substance, a circumstance that renders it unfit to be the oxidizer in an explosive agent in common use. The nitrate is therefore preferred on the ground of safety. Saltpetre, or nitrate of potash, consists, as already pointed out, of the metal potassium in combination with the substances nitrogen and oxygen. Of these, the last only is directly concerned in the explosion; but the two former, and especially the nitrogen, act indirectly to intensify its effects in a manner that will be explained hereafter.

The chemical formula for nitrate of potash is KNO_3, which signifies that three atoms of oxygen exist in this body in combination with one atom of nitrogen and one atom of kalium or potassium. As the atomic weights of these substances are 16, 14, and 39 respectively, the weight of the molecule is 101, that is, in 101 lb. of nitrate of potash there are 39 lb. of potassium, 14 lb. of nitrogen, and $(16 \times 3) = 48$ lb. of oxygen. Hence the proportion of oxygen in nitrate of potash is by weight 47·5 per cent. It will be seen from this proportion that to obtain 1 lb. of oxygen, 2·1 lb. of the nitrate must be decomposed.

The carbon of gunpowder is obtained from wood charcoal, the light woods, such as alder, being preferred for that purpose. The composition of the charcoal varies somewhat according to the degree to which the burning has been carried, the effect of the burning being to drive out the hydrogen and the oxygen. But, generally, the composition of gunpowder charcoal is about 80 per cent. carbon, 3·25 per cent. hydrogen, 15 per cent. oxygen, and 1·75 per cent. ash. Knowing the composition of the charcoal, it is easy to calculate the proportion of saltpetre required in the explosive mixture.

Thus far we have considered gunpowder as composed of charcoal and saltpetre only. But in this compound, combustion proceeds too slowly to give explosive effects. Were the chlorate of potash used instead of the nitrate, the binary compound would be sufficient. The slowness of combustion in the nitrate mixture is due to the comparatively stable character of that body. To accelerate the breaking up of the nitrate, a quantity of sulphur is mixed up with it in the compound. This substance possesses the property of burning at a low temperature. The proportion of sulphur added varies from 10 per cent. in powder used in fire-arms, to 20 per cent. in that employed for blasting purposes. The larger the proportion of sulphur, the more rapid, within certain limits, is the combustion. Thus ordinary gunpowder is a ternary compound, consisting of charcoal, saltpetre, and sulphur.

As the composition of charcoal varies, it is not practicable to determine with rigorous accuracy the proportion of saltpetre required in every case; a mean value is therefore assumed, the proportions adopted being about—

Charcoal	15
Saltpetre	75
Sulphur	10
	100

With these proportions, the carbon should be burned to carbonic acid, and the sulphur should be all taken up by the potassium. Powder of this composition is used for fire-arms. For blasting purposes, as before remarked, the proportion of sulphur is increased at the expense of the saltpetre, in order to quicken combustion and to lessen the cost, to 20 per cent. as a maximum. With such proportions, some of the carbon is burned to carbonic oxide only, and some of the sulphur goes to form sulphurous acid, gases that are particularly noisome to the miner.

It is essential to the regular burning of the mixture that the ingredients be finely pulverized and intimately mixed. The manufacture of gunpowder consists of operations for bringing about these results. The several substances are broken up by mechanical means, and reduced to an impalpable powder. These are then mixed in a revolving drum, and afterwards kneaded into a paste by the addition of a small quantity of water. This paste is subjected to pressure, dried, broken up, and granulated; thus, the mixing being effected by mechanical means, the compound is called a mechanical mixture. It will be observed that in a mechanical mixture the several ingredients are merely in contact, and are not chemically united. They may therefore be separated if need be, or the proportions may be altered in any degree. Mechanical mixtures, provided the bodies in contact have no chemical action one upon another, are stable, that is, they are not liable, being made up of simple bodies, to decompose spontaneously.

Chemical Compounds.—In a mechanical mixture, as we have seen, the elements which are to react one upon another are brought together in separate bodies. In gunpowder, for example, the carbon is contained in the charcoal, and the oxygen in the saltpetre. But in a chemical compound, these elements are brought together in the same body. In a mechanical mixture, we may put what proportion of oxygen we please. But elements combine chemically only in certain definite proportions, so that in the chemical compound we can introduce only a certain definite proportion of oxygen. The oxygen in saltpetre is in chemical combination with the potassium and the nitrogen, and, as we have already seen, these three substances hold certain definite proportions one to another. That is, to every atom of potassium, there are one atom of nitrogen and three atoms of oxygen. Or, which amounts to the same thing, in 1 lb. of saltpetre, there are 0·386 lb. of potassium, 0·139 lb. of nitrogen, and 0·475 lb. of oxygen. Moreover, these elements occupy definite relative positions in the molecule of saltpetre. But in the mechanical mixture, the molecules of which it is made up have no definite relative positions. Even if the three substances—charcoal, saltpetre, and sulphur—of which gunpowder is composed, could be so finely divided as to be reduced to their constituent molecules, the relative position of these would be determined by the mixing, and it would be impossible so to distribute them that each should find itself in immediate proximity to those with which it was to combine. But so far are we from being able to divide substances into their constituent molecules, that when we have reduced them to an impalpable powder, each particle of that powder contains a large number of molecules. Thus, in a mechanical mixture, we have groups of molecules of one substance mingled irregularly with groups of molecules of another substance, so that the atoms which are to combine are not in close proximity one to another, but, on the contrary, are, many of them, separated by wide intervals. In the chemical compound, however, the atoms are regularly distributed throughout the whole mass of the substance, and are, relatively to one another, in the most favourable position for combining. Viewed from this point, the chemical compound may be regarded as a perfect mixture, the mechanical mixture being a very imperfect one. This difference has an important influence on the effect of an explosion. All the atoms in a chemical compound enter at once into their proper combinations, and these combinations take place in an inconceivably short space of time, while, in a mechanical mixture, the combinations are less direct, and are much less rapidly effected. This is the reason why the former is more violent in its action than the latter. The one is crushing and shattering in its effects, the other rending and projecting. The compound gives a sudden blow; the mixture applies a gradually increasing pressure. It is this sudden action of the compound that allows it to be used effectively without tamping. The air, which rests upon the charge, and which offers an enormous resistance to motion at such inconceivably high velocities, serves as a sufficient tamping.

Gun-cotton may be taken as an example of a chemical compound. The woody or fibrous part of plants is called "cellulose." Its chemical formula is $C_6H_{10}O_5$, that is, the molecule of cellulose consists of six atoms of carbon in combination with ten atoms of hydrogen and five atoms of oxygen. If this substance be dipped into concentrated nitric acid, some of the hydrogen is displaced and peroxide of nitrogen is substituted for it. The product is nitrocellulose, the formula of which is $C_6H_7(NO_2)_3O_5$.

If this formula be compared with the last, it will be seen that three atoms of hydrogen have been eliminated and their place taken by three molecules of the peroxide of nitrogen NO_2; so that we now have a compound molecule, which is naturally unstable. The molecules of the peroxide of nitrogen are introduced into the molecule of cellulose for the purpose of supplying the oxygen needed for the combustion of the carbon and the hydrogen, just as the groups of molecules of saltpetre were introduced into the charcoal of the gunpowder for the combustion of the carbon and the hydrogen of that substance. Only, in the former case, the molecules of the peroxide are in chemical combination, not merely mixed by mechanical means as in the latter. The compound molecule of nitro-cellulose may be written $C_6H_7N_3O_{11}$, that is, in 297 lb. of the substance, there are (6 × 12) 72 lb. of carbon, (7 × 1) 7 lb. of hydrogen, (3 × 14) 42 lb. of nitrogen, and (11 × 16) 176 lb. of oxygen; or 24·2 per cent. carbon, 2·3 per cent. hydrogen, 14·1 per cent. nitrogen, and 59·4 per cent. oxygen. When the molecule is broken up by the action of heat, the oxygen combines with the carbon and the hydrogen, and sets the nitrogen free. But it will be observed that the quantity of oxygen present is insufficient to completely oxidize the carbon and the hydrogen. This defect, though it does not much affect the volume of gas generated, renders the heat developed, as shown in a former section, considerably less than it would be were the combustion complete, and gives rise to the noxious gas carbonic oxide.

Cotton is one of the purest forms of cellulose, and, as it may be obtained at a cheap rate, it has been adopted for the manufacture of explosives. This variety of nitro-cellulose is known as "gun-cotton." The raw cotton made use of is waste from the cotton mills, which waste, after being used for cleaning the machinery, is swept from the floors and sent to the bleachers to be cleaned. This is done by boiling in strong alkali and lime. After being picked over by hand to remove all foreign substances, it is torn to pieces in a "teasing" machine, cut up into short lengths, and dried in an atmosphere of 190° F. It is then dipped into a mixture of one part of strong nitric acid and three parts of strong sulphuric acid. The use of the sulphuric acid is, first, to abstract water from the nitric acid, and so to make it stronger; and, second, to take up the water which is formed during the reaction. After the dipping, it is placed in earthenware pots to digest for twenty-four hours, in order to ensure the conversion of the whole of the cotton into gun-cotton. To remove the acid, the gun-cotton is passed through a centrifugal machine, and subsequently washed and boiled. It is then pulped, and again washed with water containing ammonia to neutralize any remaining trace of acid. When rendered perfectly pure, it is compressed into discs and slabs of convenient dimensions for use.

Another important chemical compound is nitro-glycerine. Glycerine is a well-known, sweet, viscous liquid that is separated from oils and fats in the processes of candle-making. Its chemical formula is: $C_3H_8O_3$; that is, the molecule is composed of three atoms of carbon, in combination with eight atoms of hydrogen, and three atoms of oxygen. In other words, glycerine consists of carbon 39·1 per cent., hydrogen 8·7 per cent., and oxygen 52·2 per cent. When this substance is treated, like cellulose, with strong nitric acid, a portion of the hydrogen is displaced, and peroxide of nitrogen is substituted for it; thus the product is: $C_3H_5(NO_2)_3O_3$, similar, it will be observed, to nitro-cellulose. This product is known as nitro-glycerine. The formula may be written $C_3H_5N_3O_9$. Hence, in 227 lb. of nitro-glycerine, there are (3 × 12) 36 lb. of carbon; (5 × 1) 5 lb. of hydrogen; (3 × 14) 42 lb. of nitrogen; and (9 × 16) 144 lb. of oxygen; or 15·8 per cent. is carbon, 2·2 per cent. hydrogen, 18·5 per cent. nitrogen, and 63·5 per cent. oxygen. When the molecule is broken up by the action of heat, the oxygen combines with the carbon and the hydrogen, and sets the nitrogen free. And it will be seen that the quantity of oxygen present is more than sufficient to completely oxidize the carbon and the hydrogen. In this, the nitro-glycerine is superior to the nitro-cotton. In both of these compounds, the products of combustion are wholly gaseous, that is, they give off no smoke, and leave no solid residue.

In the manufacture of nitro-glycerine, the acids, consisting of one part of strong nitric acid and two parts of strong sulphuric acid, are mixed together in an earthenware vessel. When quite cold, the glycerine is run slowly into this mixture, which, during the process, is kept in a state of agitation, as heat is developed in the process; and, as the temperature must not rise above 48° F., the vessels are surrounded with iced water, which is kept in circulation. When a sufficient quantity of glycerine has been run into the mixture, the latter is poured into a tub of water. The nitro-glycerine being much heavier than the dilute acid mixture, sinks to the bottom; the acid liquid is then poured off, and more water added, this process being repeated until the nitro-glycerine is quite free from acid.

Nitro-glycerine is, at ordinary temperatures, a clear, nearly colourless, oily liquid, having a specific gravity of about 1·6. It has a sweet, pungent taste, and if placed upon the tongue, or even if allowed to touch the skin in any part, it causes a violent headache. Below 40° F. it solidifies in crystals.

Dynamite is nitro-glycerine absorbed in a silicious earth called kieselguhr. Usually it consists of about

75 per cent. nitro-glycerine and 25 per cent. kieselguhr. The use of the absorbent is to remove the difficulties and dangers attending the handling of a liquid. Dynamite is a pasty substance of the consistence of putty, and is, for that reason, very safe to handle. It is made up into cartridges, and supplied for use always in that form.

SECTION III.—RELATIVE STRENGTH OF THE COMMON EXPLOSIVE AGENTS.

Force developed by Gunpowder.—In the combustion of gunpowder, the elements of which it is composed, which elements, as we have seen, are carbon, hydrogen, nitrogen, oxygen, potassium, and sulphur, combine to form, as gaseous products, carbonic acid, carbonic oxide, nitrogen, sulphuretted hydrogen, and marsh gas or carburetted hydrogen, and, as solid products, sulphate, hyposulphite, sulphide, and carbonate of potassium. Theoretically, some of these compounds should not be produced; but experiment has shown that they are. It has also been ascertained that the greater the pressure, the higher is the proportion of carbonic acid produced, so that the more work the powder has to do, the more perfect will be the combustion, and, consequently, the greater will be the force developed. This fact shows that overcharging is not only very wasteful of the explosive, but that the atmosphere is more noxiously fouled thereby.

The same remark applies even more strongly to gun-cotton and the nitro-glycerine compounds.

The careful experiments of Messrs. Noble and Abel have shown that the explosion of gunpowder produces about 57 per cent. by weight of solid matters, and 43 per cent. of permanent gases. The solid matters are, at the moment of explosion, in a fluid state. When in this state, they occupy 0·6 of the space originally filled by the gunpowder, consequently the gases occupy only 0·4 of that space. These gases would, at atmospheric pressure and 32° F. temperature, occupy a space 280 times that filled by the powder. Hence, as they are compressed into 0·4 of that space, they would give a pressure of $\frac{280}{0 \cdot 4} \times 15 = 10{,}500$ lb., or about 4·68 tons to the square inch. But a great quantity of heat is liberated in the reaction, and, as it was shown in a former section, this heat will enormously increase the tension of the gases. The experiments of Noble and Abel showed that the temperature of the gases at the instant of explosion is about 4000° F. Thus the temperature of $32° + 461°{\cdot}2 = 493°{\cdot}2$ absolute, has been raised $\frac{4000}{493 \cdot 2} = 8 \cdot 11$ times, so that the total pressure of the gases will be $4 \cdot 68 \times 8 \cdot 11 = 42 \cdot 6$ tons to the square inch. And this pressure was, in the experiments referred to, indicated by the crusher-gauge. When, therefore, gunpowder is exploded in a space which it completely fills, the force developed may be estimated as giving a pressure of about 42 tons to the square inch.

Relative Force developed by Gunpowder, Gun-cotton, and Nitro-glycerine.—Unfortunately no complete experiments have hitherto been made to determine the absolute force developed by gun-cotton and nitro-glycerine. We are, therefore, unable to estimate the pressure produced by the explosion of those substances, or to make an accurate evaluation of their strength relatively to that of gunpowder. It should, however, be borne in mind that a correct estimate of the pressure produced to the square inch would not enable us to make a full comparison of the *effects* they were capable of causing. For though, by ascertaining that one explosive gives twice the pressure of another, we learn that one will produce twice the effect of another; yet it by no means follows from that fact that the stronger will produce no more than twice the effect of the weaker. The rending effect of an explosive depends, in a great measure, on the rapidity with which combustion takes place. The force suddenly developed by the decomposition of the chemical compounds acts like a blow, and it is a well-known fact that the same force, when applied in this way, will produce a greater effect than when it is applied as a gradually increasing pressure. But some calculations have been made, and some experiments carried out, which enable us to form an approximate estimate of the relative strength of these explosive substances.

Messrs. Roux and Sarrau give the following as the result of their investigations, derived from a consideration of the weight of the gases generated and of the heat liberated. The substances are simply exploded, and the strength of gunpowder is taken as unity.

Substance.	Relative Weight of Gases.	Heat in Units liberated from 1 lb.	Relative Strength.
Gunpowder	0·414	1316	1·00
Gun-cotton	0·850	1902	3·00
Nitro-glycerine ..	0·800	3097	4·80

The relative strength is that due to the volume of the gases and the heat, no account being taken of the increased effect due to the rapidity of the explosion.

Alfred Noble has essayed to appreciate the effects of these different explosives by means of a mortar loaded with a 32-lb. shot and set at an angle of 10°, the distances traversed by the shot being taken as the results to be compared. Considered, weight for weight, he estimates as follows the relative strengths of the substances compared, gunpowder being again taken as unity:—

Gunpowder	1·00
Gun-cotton	2·84
Dynamite	2·89
Nitro-glycerine	4·00

The relative strength, bulk for bulk, is, however, of greater importance in rock blasting. This is easily computed from the foregoing table and the specific gravity of the substances, which is 1·00 for gunpowder and compressed gun-cotton, 1·60 for nitro-glycerine, and 1·65 for dynamite. Compared in this way, bulk for bulk, these explosives range as follows:—

Gunpowder	1·00
Gun-cotton	2·57
Dynamite	4·23
Nitro-glycerine	5·71

Hence, for a given height of charge in a bore-hole, gun-cotton exerts about 2½ times the force of gunpowder, and dynamite about 4¼ times that force.

SECTION IV.—MEANS OF FIRING THE COMMON EXPLOSIVE AGENTS.

Action of Heat.—We have seen that the oxygen required for the combustion of the carbon in gunpowder is stored up in the saltpetre. So long as the saltpetre remains below a certain temperature, it will retain its oxygen; but when that temperature is reached, it will part with that element. To fire gunpowder, heat is therefore made use of to liberate the oxygen, which at once seizes upon the carbon with which it is in presence. The means employed to convey heat to an explosive have been described in the preceding chapter. It is necessary to apply heat to one point only of the explosive; it is sufficient if it be applied to only one grain. That portion of the grain which is thus raised in temperature begins to "burn," as it is commonly expressed, that is, this portion enters at once into a state of combustion, the saltpetre giving up its oxygen, and the liberated oxygen entering into combination with the carbon. The setting up of this action is called "ignition." The hot gases generated by the combustion set up ignite other grains surrounding the one first ignited; the gases resulting from the combustion of these ignite other grains; and, in this way, ignition is conveyed throughout the mass. Thus the progress of ignition is gradual. But though it takes place, in every case, gradually, if the gases are confined within the space occupied by the powder, it may be extremely rapid. It is easy to see that the gases evolved from a very small number of grains are sufficient to fill all the interstices, and to surround every individual grain of which the charge is composed. But besides this ignition from grain to grain, the same thing goes on from the outside to the inside of each individual grain, the grain burning gradually from the outside to the inside in concentric layers. The successive ignitions in this direction, however, of layer after layer, is usually described as the progress of combustion. Thus the time of an explosion is made up of that necessary for the ignition of all the grains, and of that required for their complete combustion.

The time of ignition is determined in a great measure by the proportion which the interstices, or empty spaces between the grains, bear to the whole space occupied by the powder. If the latter be in the form of an impalpable dust, ignition cannot extend throughout the mass in the manner we have described; but we shall have merely combustion proceeding from grain to grain. If, on the contrary, the powder be in large spherical grains or pellets, the interstices will be large, and the first gases formed will flash through these, and ignite all the grains one after another with such rapidity that ignition may be regarded as simultaneous. Thus the time of ignition is shortened by increasing the size of the grains and approximating the latter to the spherical form.

But the time of combustion is determined by conditions contrary to these. As combustion proceeds gradually from the outside to the inside of a grain, it is obvious that the larger the grain is, the longer will be the time required to burn it in. Also it is evident that if the grain be in the form of a thin flake, it will be burned in a much shorter time than if it be in the spherical form. Thus the conditions of rapid ignition and rapid combustion are antagonistic. The minimum time of explosion is obtained when the grains are irregular in shape and only sufficiently large to allow a fairly free passage to the hot gases. There are other conditions which influence the time of combustion; among them is the *density* of the grain. This is obvious, since the denser the grain, the greater is the quantity of material to be consumed. But besides this, combustion proceeds more slowly through a dense grain than through an open one. The presence of moisture also tends to retard combustion.

The progress both of ignition and of combustion is accelerated, not uniform. In proportion as the grains are ignited, the gases evolved increase in volume, and as the progress of combustion continues to generate gases, the tension of these increases, until, as we have seen, the pressure rises as high as 42 tons to the square inch. As the pressure increases, the hot gases are forced more and more deeply into the grains, and combustion, consequently, proceeds more and more rapidly.

Detonation.—By detonation is meant the simultaneous breaking up of all the molecules of which the explosive substance is composed. Properly the term is applicable to the chemical compounds only. But it is applied to gunpowder to denote the simultaneous ignition of all the grains. The mode of firing by detonation is obviously very favourable to the rending effect required of blasting powder, since it reduces to a minimum the time of explosion. It is brought about, in all cases, by means of an initial explosion. The detonator, which produces this initial explosion, consists of an explosive compound, preferably one that is quick in its action, contained within a case sufficiently strong to retain the gases until they have acquired a considerable tension. When the case bursts, this tension forces them instantaneously through the interstices of the powder, and so produces simultaneous ignition. A pellet of gun-cotton, or a cartridge of dynamite, the latter especially, makes a good detonator for gunpowder. Fired in this way, very much better effects may be obtained from gunpowder than when fired in the usual manner. Indeed, in many kinds of rock, more work may be done with it than with gun-cotton or with dynamite.

The action of a detonator upon a chemical compound is different. In this case, the explosion seems to be due more to the vibration caused by the blow than by the heat of the gases from the detonator. Probably both of these causes operate in producing the effect. However this may be, the fact is certain that under the influence of the explosion of the detonator, the molecules of a chemical compound, like nitro-glycerine, are broken up simultaneously, or at least, so nearly simultaneously, that no tamping is needed to obtain the full effect of the explosion. Dynamite is always, and gun-cotton is usually, fired by means of a detonator. A much larger quantity of explosive is needed to detonate gunpowder than is required for dynamite, or gun-cotton, since, for the former explosive, a large volume of gases is requisite. Dynamite detonators usually consist of from six to nine grains of fulminate of mercury contained in a copper cap, as described in the preceding chapter. Gun-cotton detonators are similar, but have a charge of from ten to fifteen grains of the fulminate. An insufficient charge will only scatter the explosive instead of firing it, if it be unconfined, and only explode it without detonation, if it be in a confined space.

SECTION V.—SOME PROPERTIES OF THE COMMON EXPLOSIVE AGENTS.

Gunpowder.—The combustion of gunpowder, as we have seen, is gradual and comparatively slow. Hence its action is rending and projecting rather than shattering. This constitutes one of its chief merits for certain purposes. In many quarrying operations, for instance, the shattering action of the chemical compounds would be very destructive to the produce. In freeing blocks of slate, or of building stone, a comparatively gentle lifting action is required, and such an action is exerted by gunpowder. Moreover, this action may be modified by using light tamping, or by using no tamping, a mode of employing gunpowder often adopted in slate quarries. The effect of the violent explosives cannot be modified in this way.

Gunpowder is injured by moisture. A high degree of moisture will destroy its explosive properties altogether, so that it cannot be used in water without some protective covering. Even a slight degree of moisture, as little as one per cent. of its weight, materially diminishes its strength. For this reason, it should be used, in damp ground, only in cartridges. This is, indeed, the most convenient and the most economical way of using gunpowder in all circumstances. It is true that there is a slight loss of force occasioned by the empty space around the cartridge, in holes that are far from circular in shape. But at least as much will be lost without the cartridge from the moisture derived from the rock, even if the hole be not wet. But in all downward holes, the empty spaces may be more or less completely filled up with dry loose sand.

The products of the explosion of gunpowder are partly gaseous, partly solid. Of the former, the most important are carbonic acid, carbonic oxide, and nitrogen. The sulphuretted and the carburetted hydrogen are formed in only small quantities. The carbonic oxide is a very noxious gas; but it is not formed in any considerable quantity, except in cases of overcharging. The solid products are compounds of potassium and sulphur, and potassium and carbon. These constitute the smoke, the dense volumes of which characterize the explosion of gunpowder. This smoke prevents the immediate return of the miner to the working face after the blast has taken place.

Gun-cotton.—The combustion of gun-cotton takes place with extreme rapidity, in consequence of which its action is very violent. Its effect is rather to shatter the rock than to lift it out in large blocks. This quality renders it unsuitable to many quarrying operations. In certain kinds of weak rock, its disruptive effects are inferior to those produced by gunpowder. But in ordinary mining operations, where strong tough rock has to be dealt with, its superior strength and quickness of action, particularly the latter quality, produce much greater disruptive effect than can be obtained from gunpowder. Moreover, its shattering action tends to break up into small pieces the rock dislodged, whereby its removal is greatly facilitated.

Gun-cotton may be detonated when in a wet state by means of a small quantity of the dry material. This is a very important quality, inasmuch as it allows the substance to be used in a wet hole without protection, and conduces greatly to the security of those who handle it. When in the wet state, it is uninflammable, and cannot be exploded by the heaviest blows. Only a powerful detonation will bring about an explosion in it when in the wet state. It is, therefore, for safety, kept and used in that state. Since it is insensible to blows, it may be rammed tightly into the bore-hole, so as to fill up all empty spaces. The primer of dry gun-cotton, however, which is to detonate it, must be kept perfectly dry, and handled with caution, as it readily detonates from a blow. Gun-cotton, when ignited in small quantities in an unconfined space, burns fiercely, but does not explode.

The products of the combustion of gun-cotton are:—carbonic acid, carbonic oxide, water, and a little carburetted hydrogen or marsh-gas. On account of the insufficiency of oxygen, already pointed out, a considerable proportion of carbonic oxide is formed, which vitiates the atmosphere into which it is discharged. Overcharging, as in the case of gunpowder, causes an abnormal quantity of the oxide to be formed.

Dynamite.—As combustion takes place more rapidly in nitro-glycerine than in gun-cotton, the effects of dynamite are more shattering than those of the latter substance. Gun-cotton holds, indeed, a mean position in this respect between dynamite, on the one hand, and gunpowder on the other. Dynamite is, therefore, even less suitable than gun-cotton for those uses which are required to give the produce in large blocks. But in very hard and tough rock, it is considerably more effective than gun-cotton, and, under some conditions, it will bring out rock which gun-cotton fails to loosen.

Dynamite is unaffected by water, so that it may be used in wet holes; indeed, water is commonly used as tamping, with this explosive. In upward holes, where water cannot, of course, be used, dynamite is generally fired without tamping, its quick action rendering tamping unnecessary.

The pasty form of dynamite constitutes a great practical advantage, inasmuch as it allows the explosive to be rammed tightly into the bore-hole so as to fill up all empty spaces and crevices. This is important, for it is obvious that the more compactly the charge is placed in the hole, the greater will be the effect of the explosion. Moreover, this plastic character renders it very safe to handle, as blows can hardly produce sufficient heat in it to cause explosion. If a small quantity of dynamite be placed upon an anvil and struck with a hammer, it explodes readily; but a larger quantity so struck does not explode, because the blow is cushioned by the kieselguhr. If ignited in small quantities in an unconfined space, it burns quietly without explosion.

If dynamite be much handled out of the cartridges, it causes violent headaches; and the same effect is produced by being in a close room in which there is dynamite in the unfrozen state.

Dynamite possesses one quality which places it at a disadvantage with respect to other explosives, namely, that of freezing at a comparatively high temperature. At about 40° F. the nitro-glycerine solidifies, and the dynamite becomes chalky in appearance. In this state, it is exploded with difficulty, and, consequently, it has to be thawed before being used. This may be safely done with hot water; performed in any other way the operation is dangerous.

The products of the combustion of dynamite are carbonic acid, carbonic oxide, water, and nitrogen. As, however, there is more than a sufficiency of oxygen in the compound, but little of the oxide is formed when the charge is not excessive. If, therefore, dynamite be properly detonated, and overcharging be avoided, its explosion will not greatly vitiate the atmosphere. But if it be only partially detonated hypo-nitric fumes are given off, which have a very deleterious effect upon the health. It is, thus, of the highest importance that complete detonation should be effected, not merely to obtain the full effect of the explosive, but to avoid the formation of this noxious gas. This may be done by using a detonator of sufficient strength, and placing it well into the primer.

Firing Points of the Common Explosive Compounds.—The following table shows the temperatures at which the commonly used compounds explode :—

	When slowly Heated.	When suddenly Heated.
Gunpowder	..	from 500° to 540°
Gun-cotton	360°	482°
Kieselguhr dynamite ..	356°	446°
Cellulose dynamite	342°	446°

Cotton powder explodes at the same temperatures as gun-cotton, and lithofracteur at the same temperature as kieselguhr dynamite.

SECTION VI.—SOME VARIETIES OF THE NITRO-CELLULOSE AND THE NITRO-GLYCERINE COMPOUNDS.

Nitrated Gun-cotton.—It has been shown that gun-cotton contains an insufficient quantity of oxygen for its complete combustion. To furnish that which is wanting, gun-cotton has sometimes incorporated with it a certain proportion of nitrate of potash, or of nitrate of baryta. This compound, which, it will be observed, is at once a chemical compound and a mechanical mixture, is known as "nitrated gun-cotton."

Cotton Powder, or Tonite.—The explosive which is now well known as "tonite" or "cotton powder," is essentially nitrated gun-cotton. It is produced in a granulated form, and is compressed into cartridges of various dimensions to suit the requirements of practice. The convenient form in which tonite is made up, ready to the miner's hand, has greatly contributed towards bringing it into favour. But irrespective of this, the fact of its being so highly compressed as to give it a density equal, or nearly equal, to dynamite gives it a decided advantage over the other nitro-cotton compounds as they are at present used.

Schultze's Powder.—In Schultze's powder, the cellulose is obtained from wood. The wood is first sawn into sheets, about $\frac{1}{16}$ inch thick, and then passed through a machine, which punches it up into grains of a uniform size. These are deprived of their resinous matters by a process of boiling in carbonate of soda, and are further cleansed by washing in water, steaming, and bleaching by chloride of lime. The grains, which are then pure cellulose, are converted into nitro-cellulose in the same way as cotton, namely, by being treated with a mixture of nitric and sulphuric acids. The nitro-cellulose thus produced is subsequently steeped in a solution of nitrate of potash. Thus the finished compound is similar in character to nitrated gun-cotton.

Lithofracteur.—Lithofracteur is a nitro-glycerine compound in which a portion of the base is made explosive. In dynamite, the base, or absorbent material, is, as we have said, a silicious earth, called "kieselguhr." In lithofracteur, the same substance is used; but in addition, a mixture of nitrate of baryta and charcoal, a kind of gunpowder, is introduced. The object of employing this explosive mixture is to increase the force of the explosion, the kieselguhr being an inert substance. Obviously this object would be attained if the explosive mixture possessed the same absorbent power as the kieselguhr. But unfortunately it does not, and, as a consequence, less nitro-glycerine is used. Thus what is gained in the absorbent is lost in the substance absorbed. The composition of lithofracteur varies somewhat; but its average proportion of ingredients are the following:—

Nitro-glycerine	52·50
Nitrate of baryta	16·40
Charcoal	2·85
Sulphur	25·75
Kieselguhr	22·50
	100·00

Brain's Powder.—Brain's powder is a nitro-glycerine compound, similar in character to lithofracteur. The exact composition of the base has never been published, so far as relates to the proportions of the ingredients. But it is composed of chlorate of potash, charcoal, and nitrated sawdust. The proportion of nitro-glycerine never exceeds 40 per cent. Horseley's powder contains about the same proportion of nitro-glycerine in a base of chlorate of potash and nut-galls.

Cellulose Dynamite.—In Germany, gun-cotton is used as an absorbent for nitro-glycerine, the compound being known as "Cellulose dynamite." It is chiefly used for primers to explode frozen dynamite. It is more sensitive to blows than the kieselguhr dynamite.

CHAPTER III.

THE PRINCIPLES OF ROCK BLASTING.

Line of Least Resistance.—The pressure of a fluid is exerted equally in all directions; consequently the surrounding mass subjected to the force will yield, if it yield at all, in its weakest part, that is, the part which offers least resistance. The line along which the mass yields, or line of rupture, is called the "line of least resistance." If the surrounding mass were perfectly homogeneous, it would always be a straight line, and it would be the shortest distance from the centre of the charge to the surface. Such, however, is never the case, and the line of rupture is, therefore, always a more or less irregular line, and often much longer than that from the centre direct to the surface. It will be obvious, on reflection, that the line of least resistance will be greatly dependent upon (1) the texture of the rock, which may vary from one point to another; (2) its structure, which renders it more easily cleavable in one direction than in another; (3) the position, direction, and number of the joints, which separate the rock into more or less detached portions; and (4) the number and relative position of the unsupported faces of the rock. All these circumstances must be ascertained, and the position and the direction of the bore-hole determined in accordance with them, in order to obtain the maximum effect from a given quantity of explosive. It must not be supposed, however, that this is a labour involving minute examination and long consideration. On the contrary, a glance is generally sufficient to enable the trained eye to estimate the value of those circumstances, and to determine accordingly the most effective position for the shot. In practice, the line of least resistance is taken as the shortest distance from the centre of the charge to the surface of the rock, unless the existence of joint planes, a difference of texture, or some other circumstance, shows it to lie in some other direction.

Force required to cause Disruption.—When the line of least resistance is known, it remains to determine the quantity of the explosive compound required to overcome the resistance along that line. This matter is one of great importance, for not only is all excess waste, but this waste will be expended in doing mischief. In mining operations, the dislodged rock is violently projected, and the air is vitiated in an unnecessary degree; and in quarrying, stones are shattered which it is desirable to extract in a sound state. The evil effects of overcharging, in occasioning the formation of noxious gases, was pointed out in the last chapter. Of course it is not possible so to proportion a charge to the resistance that the rock shall be just lifted out, and no more; because neither the force developed by the charge, nor the value of the resistance can be known with precision. But a sufficient approximation may be easily arrived at to enable us to avoid the loud report that is indicative of wasted force.

Charges of an explosive compound of uniform strength produce effects that vary as the weight of those charges, that is, a double charge will move a double mass. And, as homogeneous masses vary as the cube of any similar line within them, the general rule is established that charges of powder capable of producing the same effects are to each other as the cubes of the lines of least resistance. Generally, the quantity of black blasting powder requisite to overcome the resistance will vary from $\frac{1}{20}$ to $\frac{1}{30}$ of the cube of the line of least resistance, the latter being measured in feet and the former in pounds. Thus, if the rock to be blasted be moderately strong limestone, for example, and the shortest distance from the centre of the charge to the surface of the rock be 3 feet, we shall have $3 \times 3 \times 3 = 27$, the cube of the line, and $\frac{27}{25}$ lb. $= 1\frac{2}{25}$ lb., or about 1 lb. 1 oz., as the weight of the powder required. If dynamite be used, and we assume it to be four times as strong as common black powder, of course, only one-fourth of this quantity will be required. Also if gun-cotton, or cotton-powder, be used, and we assume its strength to be three times that of black powder, one-third only will be needed. Again, if Curtiss' and Harvey's new extra-strong mining powder fired by a detonator be employed, we may assume it to be twice as strong as common black powder fired by the ordinary means, and consequently we shall need only one-half the quantity indicated by the formula.

It is neither practicable nor desirable that such calculations and measurements as these should be made for every blast; their practical value lies in this, namely, that if the principles involved in them be clearly understood, the blaster is enabled to proportion his charges *by sight* to the resistance to be overcome, with a sufficient degree of precision. A few experiments in various kinds of rock, followed by some practice, will enable a man to acquire this power.

As it is a common and a convenient practice to make use of the bore-hole as a measure of the quantity of explosive to be employed, we have calculated the following table :—

Diameter of the Hole.	Black Powder in 1 inch.	Gun-cotton in 1 inch.	Dynamite (or Tonite) in 1 inch.
ins.	ozs.	ozs.	ozs.
1	0·419	0·419	0·670
1¼	0·654	0·654	1·046
1½	0·942	0·942	1·507
1¾	1·283	1·283	2·053
2	1·675	1·675	2·680
2¼	2·120	2·120	3·392
2½	2·618	2·618	4·189
2¾	3·166	3·166	5·066
3	3·769	3·769	6·030

Conditions of Disruption.—Having explained the law according to which the elastic gases evolved by an explosion act upon the surrounding rock, and shown how the force required to cause disruption may be calculated, it now remains to consider the conditions under which disruption may take place. Suppose a block of unfissured rock detached on all sides, as shown in plan, in Fig. 40, and a bore-hole placed in the centre of this block. If a charge be fired in this position, the lines of rupture will radiate from the centre towards any two, or towards all four of the unsupported faces of the block, because the forces developed will act equally in all directions, and the lines of rupture will be those of least resistance. Evidently this is the most favourable condition possible for the charge, since the rock offers an unsupported face on every side; and it is evident that the line of rupture must reach an unsupported face to allow of dislodgement taking place. Suppose, again, as shown in Fig. 41, the block to be unsupported on three sides only, and the charge

Fig. 40.

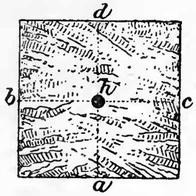
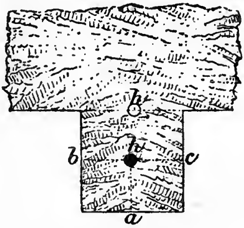


Fig. 41.

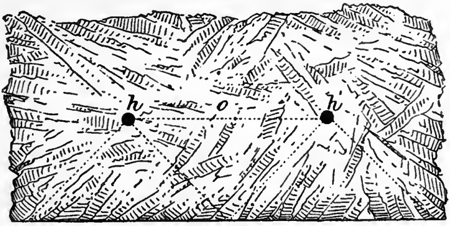


placed at *h*. In this case, the lines of rupture may run to any two, or to all three, of the unsupported faces; and hence this will be the next most favourable condition for the action of the charge. The greatest useful effect, however, will be obtained in this case by placing the charge farther back at *h'*, when the lines of rupture must necessarily run to the opposite faces *b c*, and, consequently, the whole of the block will be dislodged. Assume another case, in which the rock is unsupported upon only two sides, as shown in Fig. 42, and the charge placed at *h*. In this case, the lines of rupture must run to each of the unsupported faces *a b*. Thus, it is evident that this condition, though still a favourable one for the good effect of the charge, is inferior to the preceding. As rock is never homogeneous in composition nor uniform in texture, the lines of rupture, which, as before remarked, will be those of least resistance, may reach the faces at any point, as at *m n*, *m' n'*, or any point intermediate between these. But it will be seen that the useful effect will be greatest when these lines, radiating from the charge, make an angle of 180°, or, in other words, run in directly contrary directions, and that the useful effect diminishes with the angle made by these lines of rupture. Suppose, again, the rock to be unsupported upon one side only, as shown

Fig. 42.

in Fig. 43, and the charge placed at h. In this case, the lines of rupture must run to the face a, and the condition must therefore be considered as less favourable

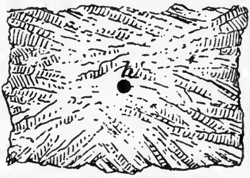
FIG. 43.



than the preceding. As in those cases, the useful effect will depend upon the angle made by the lines of rupture $h\,m$ and $h\,n$, which angle may be very small, and which must necessarily be much less than 180°. A greater effect may be obtained, under this condition, by firing several charges simultaneously. If, for example, we have two charges placed, one at h, and the other at h', and fired successively, the lines of rupture will run in or near the directions $h\,m$, $h\,n$, $h'\,m'$, $h'\,n'$, and the portion of rock dislodged will be $m\,h\,n\,h'\,n'$. But if these two charges be fired simultaneously, the lines of rupture will be $h\,m$, $h\,o$, $h'\,o$, $h'\,n'$, and the mass of rock dislodged will be $m\,h\,h'\,n'$. Simultaneous firing is in this way productive of a greatly increased useful effect in numerous cases, and the mining engineer, and the quarryman especially, will do well to direct their attention to this source of economy. There is yet another case to be considered, in which the conditions are still less favourable. Suppose two unsupported faces at right angles to each other, and the charge placed at *h*, as shown in Fig. 44. In this case, the lines of rupture will run to each of the two unsupported faces; but as these lines must necessarily make a very small angle with each other—for the length of the lines increases rapidly with the angle—the useful effect will be less than in the last case. It follows, therefore, that this is the most unfavourable condition possible, and as such it should be avoided in practice.

FIG. 44.

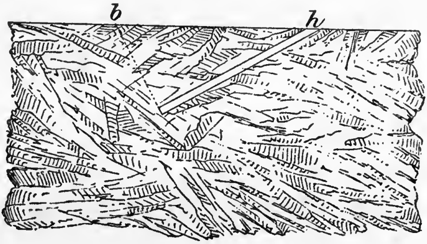
FIG. 45.



In the foregoing considerations, the holes have been assumed to be vertical, and for this reason the unsupported face which is perpendicular to the hole, that is, the face into which the hole is bored, has been neglected. For it is evident that, under the conditions assumed, the lines of rupture cannot reach this face, which, therefore, has practically no existence. Suppose, for example, a bore-hole placed at *h*, in Fig. 45, and the rock to be supported upon every side except that at right angles to the hole.

The forces acting perpendicularly to the direction of the bore-hole are opposed on all sides by an infinite resistance. Hence, in this case, either the tamping will be blown out, or, if the forces developed are unequal to the work, no effect will be produced beyond a slight enlargement of the hole at the base. This, however, is a case of frequent occurrence in practice, and it becomes necessary to adopt measures for making this unsupported face available. Evidently this object can be attained only by so directing the bore-hole that a line perpendicular to it may reach the face; that is, the line of the bore-hole must make with the unsupported face an angle less than 90°. This direction of the bore-hole is shown in Fig. 46, which may be regarded as a sectional elevation of Fig. 45. In this case, the lines of rupture, which will run similarly to those produced in the case shown in Fig. 43, will reach the unsupported face at *b*, and the length of these lines, and consequently the depth of the excavation, for a given length of bore-hole, will depend upon the angle

Fig. 46.



which the latter makes with the face. This mode of rendering a single exposed surface available is called "angling the holes," and it is generally resorted to in shaft sinking and in driving headings. The conditions involved in "angling" are favourable to the action of strong explosives.

Example of a Heading.—To show how these principles are applied in practice, we will take a typical case of a heading, 7 feet by 9 feet, as shown in Fig. 47. In this case, we have at starting only one exposed face, which is perpendicular to the direction of the driving. Hence it is evident that we shall have to proceed by angling the holes. We might begin in any part of the exposed face; but, as it will hereafter appear, the most favourable position is the centre. We therefore begin at this point by boring a series of holes, numbered 1 on the drawing. These holes are angled towards each other; that is, the two sets of three holes vertically above each other converge in the direction of their lower ends, as shown in the sectional plan, Fig. 48. In this instance, we have assumed six holes as necessary and sufficient. But it is obvious that the number of holes, as well as their distance apart horizontally, will be determined by their depth, the tenacity of the rock, and the strength of the explosive used. When these holes are fired, a wedge-shaped portion of the rock will be forced out, and this result will be more effectually and certainly obtained if the charges be

FIG. 47.

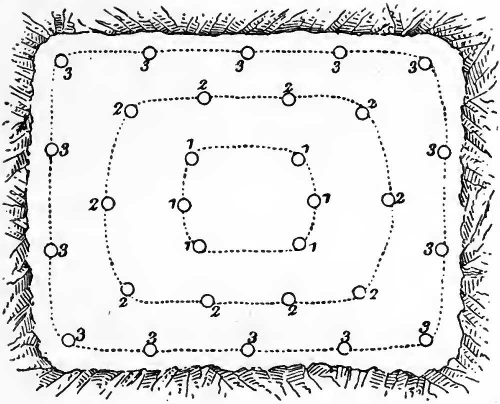
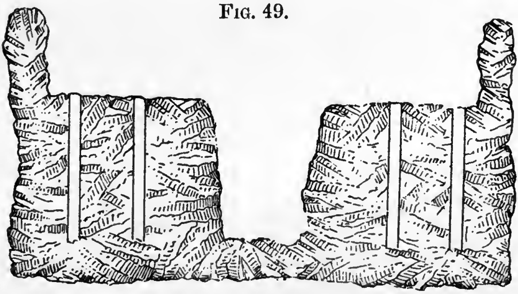


FIG. 48.

FIG. 49.



fired simultaneously. The removal of this portion of the rock is called "taking out the key." The effect of removing this key is to leave the surrounding rock unsupported on the side towards the centre; that is, another face is formed perpendicular to the first.

Having thus unkeyed the rock by the removal of this portion from the centre, it will evidently be unnecessary, except for convenience or increased effect, to angle any more of the shot-holes. The second series therefore, numbered 2 in the drawing, may be bored perpendicularly to the face of the heading. When this series is fired, the lines of rupture will all run to the unsupported face in the centre—and from hole to hole, if the shots be fired simultaneously—and the annular portion of rock included between the dotted lines 1 and 2 will be removed. If the shots be fired successively, the first will act under the condition of one unsupported face, as illustrated in Fig. 43; but as another unsupported face will be formed by the removal of the rock in front of this charge, the succeeding shots will be subject to the more favourable condition represented in Fig. 42. The firing of this second series of shots still leaves the surrounding rock unsupported towards the centre, and consequently the same conditions will exist for the third series, numbered 3 on the drawing, the firing of which series will complete the excavation. Fig. 49 shows the appearance of Fig. 48 after the firing of the central holes.

It may be remarked here that, owing to the want of homogeneity in the rock, and to the existence of joints and fissures, the outer line of rupture will not, in practice, run so regularly as indicated, in this assumed case, by the dotted lines. This circumstance will influence the position of the holes, or the quantity of explosive, in the next series, and furnish an opportunity for the exercise of judgment on the part of the blaster.

There exist also other circumstances which will influence the position and the number of the holes in a very important degree, and which therefore must be taken fully into account at every advance. One of these is the irregularity of the face of the excavation. Instead of forming an unbroken plane at right angles to the direction of the heading, or of the shaft, this face is broken up by projecting bosses and more or less deep depressions. Obviously these protuberances and cavities will influence, in no inconsiderable degree, the lines of least resistance; the latter being lengthened or shortened, or changed in direction, by the presence of the former, which give existence to unsupported faces to which the lines may radiate. These conditions must, in every case, be taken into account when determining the best position for the bore-hole. Of yet greater importance, is the existence of joint planes and bedding planes. A bed of rock may be, and frequently is, cut up by these planes into detached blocks of greater or less dimensions, according to the more or less perfect development of the different sets. Hence it becomes necessary, in determining a suitable position for blasting the charge, to consider such planes as unsupported faces, and to ascertain the direction and length of the lines of resistance under such conditions. If a charge be placed in close proximity to one of these planes, not only may the lines of rupture run in unforeseen directions, but the greater part of the force of the explosion will be lost by the escape of the gases along the plane. The same loss of force may be occasioned by the presence of a cavity, such as are of frequent occurrence in cellular or vughy rock. When the joint planes are fully developed, their existence can be ascertained by inspection; but when their development is imperfect, there may be considerable difficulty in discovering them. In such cases, the rock should be carefully inspected, and sounded with a hammer or pick. When a cavity is bored into, it may be rammed full of clay, and the boring continued through the clay; or if sufficient depth has been obtained, the charge may be placed upon the clay, which will prevent the wasteful dissipation of the gases. As none of the aforementioned circumstances occur under precisely similar conditions, no general rule of much service can be laid down; they are matters upon which the blaster must be left to use his own judgment, and to do this effectively, it is necessary that he possess some knowledge of the materials with which he deals.

Economical Considerations.—Besides the important economical considerations involved in the foregoing, there are others which claim attention. Foremost among these is the question whether, for a given effect, it be better to augment or to diminish the individual importance of the shots; that is, whether it be better to diminish the number of the holes and to increase their diameter, or to diminish their diameter and increase their number; or, again, to diminish their diameter and to increase their depth, or to increase their diameter and to diminish their number and their depth. It may be readily shown mathematically, and the results are confirmed by experience, that there is an important gain in reducing the diameter of the shot-holes to the lowest limit allowed by the strength and the gravimetric density of the explosive, and increasing their depth. The gain is mainly in the direction of a saving of labour, and it is especially remarkable in the case of machine boring. Here again we perceive the advantage of strength in the explosive agent employed.

The simultaneous firing of the shots offers several important advantages. It has already been shown how one charge aids another, under such a condition, and in what way the line of rupture is affected by it. When the shots are fired successively, each one has to *tear out* the portion of rock allotted to it; but when they are fired simultaneously, their collective force is brought to bear upon the whole mass to be dislodged. This is seen in the diagram, Fig. 43. When deep holes are used, the greater useful effect caused by simultaneous firing becomes very marked. Hence electricity associates itself naturally with machine drills and strong explosives.

Tamping.—To "tamp" a shot-hole is to fill it up above the charge of explosive with some material, which, when so applied, is called the "tamping." The object of tamping is to oppose a resistance to the escape of the gases in the direction of the bore-hole. Hence a primary condition is that the materials used shall be of a strongly resisting character. A second determining condition is that these materials shall be of easy application. This condition precludes the use of all such devices as plugs, wedges, and forms of a similar character, which have been from time to time proposed.

The only material that, in practice, has been found to satisfactorily fulfil the requirements, is rock in a broken, pulverulent, or plastic state. As, however, all rock is not equally suitable, either from the point of view of its resisting character, or from that of convenience of handling, it becomes necessary to consider which satisfies the two conditions in the most complete manner.

Though it is not easy to assign a perfectly satisfactory reason why one kind of rock substance opposes a greater resistance to motion in a bore-hole than another, yet it is certain that this resistance is mainly due to the friction among the particles of that substance. If a column of solid, hard rock, of the same diameter as the bore-hole, be driven down upon the charge, the resistance opposed by the column to the imprisoned gases will be, neglecting the weight of the former, that of the friction between the sides of the column and those of the hole. But if disintegrated rock be used, not only is an absolute motion imparted to the particles, but, on account of the varying resistances, a relative motion also. Consequently, friction occurs amongst the particles, and as the number of these is immense, the sum of the slight friction of one particle against another, and of the great friction of the outside particles against the sides of the hole, amounts to a much greater value than that of the outside particles of the solid column against the sides of the bore-hole. If this view of the facts alone be taken, it follows that dry sand is the most resistant material, and that the finer the grains, the greater will be the resistance which it offers. In practice, however, it has been found that though the resistance offered by sand tamping is very great, and though also the foregoing inference is true when the tamping is lifted by the pressure of a solid against it from below, this substance is notably inferior to some others when acted upon by an explosion of gases. The explanation of this apparent anomaly is that the gases, under the enormous tension to which they are subjected in the bore-hole, insinuate themselves between the particles, and so prevent the friction which would otherwise take place. When the readiness with which water, through the influence of gravity alone, permeates even closely compacted sand, is borne in mind, there will be no difficulty in conceiving a similar action on the part of more subtile gases in a state of extreme tension. Under such conditions as these, there is no resistance whatever due to friction, and the only resistance opposed to the escape of the gases is that proceeding from the inertia of the mass. How this resistance may be very great, we have shown in the case of air tamping. Hence, it becomes necessary to have recourse to some other material of a composition less liable to be thus acted upon, or to seek means of remedying the defect which renders such action possible.

Clay, dried either in the sun, or, preferably, by a fire, appears to fulfil the requirements of a tamping material in the fullest degree. This substance is composed of exceedingly minute grains of silicious matters, bound together by an aluminous and calcareous or ferruginous cement. Thus constituted, there are no voids between the particles, as in porous substances, and, consequently, there is no passage for the gases, the substance being impervious alike to water and gas. Hence, when this material is employed as tamping, the forces act only upon the lower surface, friction takes place among the particles, and the requisite degree of resistance is produced. By reason of its possession of this property, clay is generally used as the tamping material.

In rock blasting, it is usual to prepare the clay beforehand, and this practice is conducive both to effective results and to rapidity of tamping. The latter consideration is an important one, inasmuch as the operation, as commonly performed, requires a good deal of time. To prepare the pellets of clay, a lump is taken and rolled between the palms of the hands until it has assumed the form of a sausage, from three to four inches in length, and of the diameter of the bore-hole. These pellets are then baked until they are thoroughly dry, when they are ready for use. In making them up to the requisite diameter, a little excess should be allowed for shrinkage, since it is essential that they fit tightly into the hole. When the charge has been put in, and covered with a wad of hay, or a handful of sand or rubbish, one of these pellets is inserted and pushed home with a wooden rammer. Considerable pressure should be applied to make the clay fill the hole completely, but blows should be avoided. A second pellet is then pushed down in the same way, and the operations are repeated until the whole of the hole is tamped. To consolidate the whole, light blows may be applied to the outer pellet. It will be found advantageous to place an undried pellet immediately above the charge, because the plasticity of such a pellet enables it to fill all the irregularities of the sides of the hole, and to securely seal the passage between the sides and the tamping, along which the gases might otherwise force their way. In coal blasting, soft shale is always used for tamping, because it is ready at hand, and heavy shots are not required.

Broken brick constitutes a fairly good tamping material, especially when tempered with a little moisture; but as it is not readily procurable, its application is necessarily limited. The dust and chippings of the excavated rock are largely employed as tamping in quarries. This material, however, has but little to recommend it for the purpose beyond its readiness to hand.

It now remains to consider what means are available for remedying the defect inherent in sand as a tamping material. This constitutes a very important practical question, because if the defect can be removed, sand will constitute by far the most suitable material whenever the bore-hole has a downward direction. It can be everywhere obtained at a low cost; it may be poured into the hole as readily as water; and its application gives rise to no danger. Obviously the difficulty will be overcome if we can find suitable means for preventing the gases from penetrating the sand.

The end proposed may be successfully attained by means of the plastic clay pellet applied in the following manner. Immediately above the charge, place a handful of perfectly dry and very fine sand. This may be obtained by sifting, if not otherwise procurable. Upon this sand, force firmly down with a wooden rammer, so as to fill every irregularity, a plastic clay pellet, about four inches in length, and of the same diameter as the bore-hole, prepared by rolling between the hands in the manner already described. Above this pellet, fill the hole with dry sand. The impervious nature of the clay prevents the gases from reaching the sand, except along the line of junction of the clay with the sides of the hole. Tamped in this way, a resistance is obtained scarcely, if at all, inferior to that opposed by the most carefully placed dried clay.

By the employment of a detonator, the defect due to the porous character of sand is not removed, but its influence is greatly diminished. When detonation is produced in an explosive compound, the full force of the elastic gases is developed instantaneously; and it has already been shown that, under such conditions, the resistance occasioned by the presence of any substance in the bore-hole, even the air alone, in the case of nitro-glycerine, is sufficient to throw the chief portion of the force upon the sides of the hole. Loose sand, therefore, may be successfully employed as tamping under these conditions, since its inertia will oppose a sufficient resistance to the escape of the gases. But though the rock may be dislodged when light tampings are used with detonation, there can be no doubt that a considerable proportion of the force of the explosion is lost; and hence it will always be advantageous to tamp securely by means of the clay pellet, as already described. The highest degree of economy is to be obtained by detonating the charge, and tamping in this manner.

CHAPTER IV.

THE OPERATIONS OF ROCK BLASTING.

HAND BORING.—When the positions and the directions of the shot-holes have been determined, the operations of blasting are begun by striking a few blows with the hammer upon the spot from which the hole is to start, for the purpose of preparing the surface to receive the drill. In some cases, this preliminary operation will not be needed; but generally some preparation is desirable, especially if the surface be smooth, and the hole be to be bored at an angle with it. For the purpose of illustration, we will take the case of a hole bored vertically downwards, and will suppose the boring to be carried on by double-hand.

Boring the Shot-holes.—The surface of the rock having been prepared to receive the drill, one man sits down, and placing the shortest drill between his knees, holds it vertically, with both hands. The other man, who stands opposite, if possible, then strikes the drill upon the head with the sledge, lightly at first, but more heavily when the tool has fairly entered the rock. The man who holds the drill raises it a little after each blow, and turns it partly round, the degree of turn usually given being about one-eighth of a revolution. By this means, the hole is kept circular, and the cutting edge of the drill is prevented from falling twice in the same place. To keep the tool cool, and to convert the dust and chippings into sludge, the hole is kept partially filled with water, whenever it is inclined downwards. For this reason, downward holes are sometimes described as "wet" holes, and upward holes as "dry" holes. The presence of water greatly facilitates the work of boring. It has been found by experience that the rate of boring in a dry and in a wet hole varies as 1 : 1·5; that is, it takes one and a half times as long to bore a dry hole as to bore a wet hole. Thus, by using water, the time may be reduced by one-third. To prevent the water from spurting out at each stroke and splashing the man who holds the drill, a kind of leathern washer is placed upon the drill immediately above the hole, or a band of straw is tied round it. When the hole has become too deep for the short drill, the next length is substituted for it, which is in its turn replaced by the third or longest drill as the depth becomes greater. Each drill, on the completion of the length of hole for which it is intended, is sent away to the smithy to be re-sharpened. In very hard rock, the drills may have to be frequently changed, a circumstance that renders it necessary to have several of the same length at hand. The depth of shot-holes varies from 1 foot to 10 feet, according to the nature of the rock, the character of the excavation, and the strength of the explosive to be used. In shafts and in headings, the depth varies generally between 2 feet 6 inches and 4 feet, a common depth being 3 feet.

The débris which accumulates at the bottom of the hole must be removed from time to time to keep the rock exposed to the edge of the drill. The removal of this sludge is effected by means of the tool called a "scraper." If the sludge is in too liquid a state to allow of its ready removal by this means, a few handfuls of dust are thrown in to render the mass more viscous. The importance of keeping the bore-hole clear of sludge, and of shortening the time expended in using the scraper, has led, in some localities, to the adoption of means for rendering the sludge sufficiently viscous to adhere to the drill. When in this state, the sludge accumulates around the tool rather than beneath it, the fresh portion formed pushing the mass upward till it forms a thick coating upon the drill throughout a length of several inches. When the tool is withdrawn from the hole, this mass of débris is withdrawn with it; in this way, the employment of a scraper is rendered unnecessary. This mode of clearing the bore-hole is commonly adopted by the Hartz miners, who use slaked lime for the purpose. This lime they reduce to the consistency of thick paste by the addition of water, and they store it, covered with water, in a small tin box, which they carry with them to their work. To use this paste, they take a piece about the size of a walnut, dilute it with water, and pour it into the bore-hole. This lime paste is, for the purpose intended, very effective in friable rock, especially if it be of a granular structure, as sandstone. As the grains of sand resulting from the trituration of such rocks have no more tendency to adhere to each other than to the drill, each of them becomes covered with a coating of lime, which causes them to agglutinate into a viscous mass possessing sufficient adhesiveness to enable it to cling to the tool in the manner described.

When the hole has been bored to the required depth, it is prepared for the reception of the charge. The sludge is all carefully scraped out to clear the hole, and to render it as dry as possible. This is necessary in all cases; but the subsequent operations will be determined by the nature of the explosive, and the manner in which it is to be used. If black powder be employed in a loose state, the hole must be dried. This is done by passing a piece of rag, tow, or a wisp of hay, through the eye of the scraper and forcing it slowly up and down the hole, to absorb the moisture. If water is likely to flow into the hole from the top, a little dam of clay is made round the hole to keep it back. When water finds its way into the hole through crevices, claying by means of the "bull" must be resorted to. In such cases, however, it is far more economical of time and powder to employ the latter in waterproof cartridges. Indeed, excepting a few cases that occur in quarrying, gunpowder should always be applied in this way. For not only is a notable saving of time effected by avoiding the operations of drying the hole, but the weakening of the charge occasioned by a large proportion of the grains being in contact with moist rock is prevented. But besides these advantages, the cartridge offers security from accident, prevents waste, and affords a convenient means of handling the explosive. It may be inserted as easily into upward as into downward holes, and it allows none of the powder to be lost against the sides of the hole, or by spilling outside. These numerous and great advantages are leading to the general adoption of the cartridge.

Charging the Shot-holes.—When the hole is ready to receive the explosive, the operations of charging are commenced. If the powder be used loose, the required quantity is poured down the hole, care being taken to prevent the grains from touching and sticking to the sides of the hole. This precaution is important, since not only is the force of the grains so lodged lost, but they might be the cause of a premature explosion. As it is difficult to prevent contact with the sides when the hole is vertical, and impossible when it is inclined, recourse is had to a tin or a copper tube. This tube is rested upon the bottom of the hole, and the powder is poured in at the upper end; when the tube is raised, the powder is left at the bottom of the hole. In horizontal holes, the powder is put in by means of a kind of spoon. In holes that are inclined upwards, loose powder cannot be used. When the powder is used in cartridges, the cartridge is inserted into the hole and pushed to the bottom with a wooden rammer.

If the charge is to be fired by means of a squib, a pointed metal rod, preferably of bronze, of small diameter, called a "pricker," is placed against the side of the bore-hole, with its lower pointed end in the charge. The tamping is then put in, in small portions at a time, and firmly pressed down with the tamping iron, the latter being so held that the pricker lies in the groove. The nature of tamping has been already fully described. When the tamping is completed, the pricker is withdrawn, leaving a small circular passage through the tamping down to the charge. Care must be taken in withdrawing the pricker not to loosen the tamping, so as to close up this passage. A squib is then placed in the hole thus left, and the charge is ready for firing.

If the charge is to be fired by means of safety fuse, a piece sufficiently long to project a few inches from the hole is cut off and placed in the hole in the same position as the pricker. When the powder is in cartridges, the end of the fuse is inserted into the cartridge before the latter is pushed into the bore-hole. The fuse is held in its position during the operation of tamping by a lump of clay placed upon the end which projects from the hole, this end being turned over upon the rock. The tamping is effected in precisely the same manner as when the pricker is used.

If the charge is to be fired by electricity, the fuse is inserted into the charge, and the wires are treated in the same way as the safety fuse. When the tamping is completed, the wires are connected for firing in the manner described in a former chapter.

In all cases, before tamping a gunpowder charge placed loose in the hole, a wad of tow, hay, turf, or paper is placed over the powder previously to putting in the tamping. If the powder is in cartridges, a pellet of plastic clay is gently forced down upon the charge. Heavy blows of the tamping iron are to be avoided until five or six inches of tamping have been put in.

When gun-cotton is the explosive agent employed, the wet material which constitutes the charge is put into the shot-hole in cartridges, one after another, until a sufficient quantity has been introduced. Each cartridge must be rammed down tightly with a wooden rammer to rupture the case and to make the cotton fill the hole completely. A length of safety fuse is then cut off, and one end of it is inserted into a detonator cap. This cap is fixed to the fuse by pressing the open end into firm contact with the latter by means of a pair of nippers constructed for the purpose. The cap, with the fuse attached, is then placed into the central hole of a dry "primer," which should be well protected from moisture. When an electric fuse is used, the cap of the fuse is inserted in the same way into the primer. The primer is put into the shot-hole and pushed gently down upon the charge. As both the dry gun-cotton and the detonator may be exploded by a blow, this operation must be performed with caution.

Cotton-powder or tonite requires a somewhat different mode of handling. It is made up in a highly compressed state into cartridges, having a small central hole for the reception of the detonator cap. This cap, with the safety fuse attached in the way described, or the cap of the electric fuse, is inserted into the hole, and fixed there by tying up the neck of the cartridge with a piece of copper wire placed round the neck for that purpose. The cartridge is then pushed gently down the shot-hole, or, if a heavier charge is required, a cartridge without a detonator is first pushed down, and the "primed" cartridge put in upon it. No ramming may be resorted to, as the substance is in the dry state.

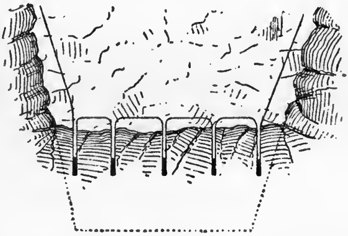
When dynamite is the explosive agent used, a sufficient number of cartridges is inserted into the shot-hole to make up the charge required. Each cartridge should be rammed home with a moderate degree of force to make it fill the hole completely. Provided a wooden rammer be employed, there is no danger to be feared from explosion. A detonator cap is fixed to the end of a piece of safety fuse, and, if water tamping is to be used, grease, or white-lead, is applied to the junction of the cap with the fuse. A "primer," that is, a small cartridge designed to explode the charge, is then opened at one end, and the detonator cap, or the cap of the electric fuse, is pushed into the dynamite to a depth equal to about two-thirds of its length, and the paper covering of the primer is firmly tied to the cap with a string. If the cap be pushed too far into the dynamite, the latter may be fired by the safety fuse, in which case the substance is only burned, not detonated. With an electric fuse this cannot occur. The same result ensues if the cap be not in contact with the dynamite. The object of tying in the cap is to prevent its being pulled out. The primer thus attached to the fuse is then pushed gently down upon the charge in the shot-hole. It should be constantly borne in mind that no ramming may take place after the detonator is inserted.

Gun-cotton and tonite require a light tamping. This should consist of plastic clay; or sand may be used in downward holes. The tamping should be merely pushed in, blows being dangerous. A better effect is obtained from dynamite when tamped in this way than when no tamping is used. In downward holes, water is commonly employed as tamping for a dynamite charge, especially in shaft sinking, when the holes usually tamp themselves. But in other cases, it is a common practice to omit the tamping altogether to save time.

Firing the Charges.—When all the holes bored have been charged, or as many of them as it is desirable to fire at one time, preparation is made for firing them. The charge-men retire, taking with them the tools they have used, and leaving only him of their number who is to fire the shots, in the case of squibs or safety fuse being employed. When this man has clearly ascertained that all are under shelter, he assures himself that his own way of retreat is open. If, for example, he is at the bottom of a shaft, he calls to those above, in order to learn whether they be ready to raise him, and waits till he receives a reply. When this reply has been given, he lights the matches of the squibs or the ends of the safety fuse, and shouts to be hauled up; or if in any other situation than a shaft, he retires to a place of safety. Here he awaits the explosion, and carefully counts the reports as they occur. After all the shots have exploded, a short time is allowed for the fumes and the smoke to clear away, and then the workmen return to remove the dislodged rock. If one of the shots has failed to explode, fifteen or twenty minutes must be allowed to elapse before returning to the place. Nine out of ten of the accidents that occur are due to these delayed shots. Some defect in the fuse, or some injury done to it, may cause it to smoulder for a long time, and the blaster, thinking the shot has missed, approaches the fuse to see the effects produced by the shots that have fired. The defective portion of the fuse having burned through, the train again starts, and the explosion takes place, probably with fatal consequences. Thus missed shots are not only a cause of long delays, but are sources of great danger. Accidents may occur also from premature explosion. In this case, the fuse is said to "run," that is, burn so rapidly that there is not sufficient time for retreat.

When the firing is to take place by means of electricity, the man to whom the duty is entrusted connects the wires of the fuses in the manner described in a former chapter, and as shown in Fig. 50. He then connects the two outer wires to

Fig. 50.



the cables, and retires from the place. Premature explosion is, in this case, impossible. When he has ascertained that all are under shelter, he goes to the firing machine, and, having attached the cables to the terminals, excites and sends off the electric current. The shots explode simultaneously, so that only one report is heard. But there is no danger to be feared from a misfire, since there can be no smouldering in an electric fuse. The face may, therefore, be approached immediately, so that no delay occurs, and there is no risk of accident. Moreover, as all the holes can be fired at the moment when all is in readiness, a considerable saving of time is effected. It is essential to the success of a blast fired by this means that a sufficient charge of electricity be generated to allow for a considerable loss by leakage. If Siemens' large dynamo-machine be used, the handle should be turned slowly till a click is heard inside, and then, not before, the cable wires should be attached to the terminals. To fire, the handle must be turned as rapidly as possible, a jerky motion being avoided. As considerable force is required, the machine must be firmly fixed. If a frictional machine be used, care must be had to give a sufficient number of turns. As this kind of machine varies greatly, according to the state of the rubbing surfaces and the degree of moisture in the atmosphere, it should always be tested for a spark before firing a blast. In this way only, can the number of turns required be ascertained. It is important that the discharging knob should be pushed in, or, as the case may be, the handle turned backward, suddenly. A slow motion may be fatal to the success of a blast. In testing Bornhardt's machine, the handle should always be turned forwards; but in firing, half the number of turns should be given in one direction and half in the other. The following table shows the number of turns required for a given number of André's fuses with Bornhardt's machine. The first column, containing the least number of turns, may be taken also for Julian Smith's machine as manufactured by the Silvertown Company with the modifications suggested by W. B. Brain.

FIRING TABLE FOR FRICTIONAL MACHINE.

	When the Machine sparks with 10 Turns.	When the Machine sparks with 12 Turns.	When the Machine sparks with 14 Turns.
Fuses in Circuit.	Number of Turns.	Number of Turns.	Number of Turns.
4	12	15	17
5	12	15	17
6	14	17	20
7	16	19	22
8	18	22	25
9	20	24	28
10	22	26	31
11	24	28	34
12	25	30	35
13	26	31	36
14	27	33	38
15	28	34	39

NOTE.—If the machine does not spark with 14 turns, the rubber should be taken out and brushed.

Places of refuge, called man-holes, are often provided in headings for the blaster to retire into;

these man-holes are small excavations made in the sides of the heading. Sometimes it is necessary to erect a shield of timbers in the heading for the protection of the men; such a shield is frequently needed to protect machine drills from the effects of a blast. In Belgium, it is a common practice to provide man-holes in the sides of a shaft as places of retreat for the men; these holes are called *caponnières*. Instead of caponnières, a hollow iron cylinder is sometimes used as a protection to the men. This cylinder is suspended in the shaft at a height of a few yards from the bottom, and is lowered as the sinking progresses. The men climb into this cylinder to await the explosion of the shots beneath them.

The workmen, on returning to the working face, remove the dislodged rock, and break down every block that has been sufficiently loosened. For this purpose, they use wedges and sledges, picks, and crowbars. And not until every such block has been removed, do they resume the boring for the second blast. Sometimes, to facilitate the removal of the rock dislodged by the shots, iron plates are laid in front of the face in a heading. The rock falling upon these plates is removed as quickly as possible, to allow the boring for the succeeding blast to commence. It is important, in the organization of work of this character, that one gang of men be not kept waiting for the completion of the labour of another.

MACHINE BORING.—In machine drilling, the operations necessarily differ somewhat in their details from those of hand boring, and, in some cases, other methods of procedure will be adopted more suitable to the requirements of machine labour. It may even be, and in most cases indeed is, inexpedient to follow closely the principles which lead to economy of the explosive substance employed, since the more restricted conditions under which machine power may be applied may point to more important gains in other directions. Thus it may be found more conducive to rapidity of execution to determine the position and the direction of the shot-holes rather to satisfy the requirements of the machine than those of the lines of least resistance; or, at least, these requirements must be allowed to have a modifying influence in determining those positions and directions. For it is obvious that holes cannot be angled with the same ease when a machine drill is used, as they can when the boring is executed by hand.

Boring the Shot-holes.—It has already been remarked that the exigencies of machine labour render it impracticable to follow closely the principles which lead to economy of labour and material in blasting. In hand boring, economy is gained by reducing to a minimum the number of holes and the quantity of explosive substance required. But in machine boring, economy is to be sought mainly in the reduction of the time needed to accomplish the driving.

Attempts have been made to assimilate the methods of machine boring to those adopted for hand labour, but the results have not been satisfactory. On the contrary, the conditions determining the position and the direction of the holes relatively to the production of the greatest useful effect have been wholly ignored in favour of those which determine the most rapid boring. This system has been attended with more satisfactory results. Another system, partaking of both the preceding, is widely adopted, and hitherto the best results have been obtained from this, which may be regarded as a compromise between conflicting conditions. Thus we have three systems of executing machine boring: one in which a single machine is used upon a support capable of holding it in any position, so as to be able to bore at any angle, and in which the holes are placed according to the lines of least resistance, as in hand boring. A second, in which several machines are fixed upon a heavy support, allowing but little lateral or angular motion, and in which the holes are placed at regular intervals apart, and bored parallel, or nearly parallel, with the axis of the excavation, irrespective of the varying nature of the rock, and the lines of least resistance. And a third, in which it is sought, by the employment of one, two, or at the most three machines, upon a simple and light support allowing the position and direction of the machine to be readily changed, to satisfy in some degree the two sets of conditions determining the two former systems, by placing the shot-holes as far in accordance with the lines of resistance as the exigencies of a fairly rapid handling of the machine will allow.

In the first of these systems, the necessity for extreme lightness in the machine is unfavourable to its efficient action, and the great length of time consumed in changing the position of the machine, so as to comply with the conditions of resistance in the rock, render it impossible to attain a much higher rate of progress than is reached by a well-regulated system of hand boring. With such a result, there is nothing to compensate the first cost of the machinery, or in any way to justify its adoption. In the second system, the time consumed in removing and fixing the machines is reduced to a minimum, and the chief portion of the time during which the machines are at the working face is, consequently, occupied in actual boring, a circumstance that is highly favourable to machine labour. Hence the rate of progress attained by this system is greatly in excess of that accomplished by hand labour; and this superiority has led to the adoption of the system in several important cases, and has also led many to regard it as the most favourable to the exigencies of machine drilling. But as the holes are bored to suit the requirements of the machine, quite irrespectively of the resistance of the rock, their positions and directions are very unfavourable to the action of the explosive. This circumstance necessitates a much greater number of holes to ensure the fracture of the rock around each charge, and hence the time saved in shifting the machines is in part lost in extra boring; besides which, the consumption of powder is enormously increased. It would, therefore, appear that the full advantages of machine boring are to be obtained from the intermediate system, if carried out in accordance with all the conditions of the case.

Assuming that we have a machine and a support of such dimensions, weight, and construction as to be capable of being readily placed in position, it is evident that we shall still require a much larger number of holes than would be needed if the boring were performed by hand, because they are not placed wholly in accordance with the lines of least resistance. In some parts of the heading, indeed, these lines will have to be wholly neglected, in order to avoid the loss of time involved in shifting the supports; for the principle upon which an intermediate system is based is to fulfil the requirements of the lines of least resistance, when that can be conveniently done, and to neglect them, when such fulfilment would involve a considerable expenditure of labour and time.

In this way, the time both for fixing and removing the machines and of boring is reduced to a minimum, and thus two conditions favourable to rapid and economical progress is ensured. It is evident that when this system is followed, the face will not require the same number of holes at each blast. Another circumstance operating to increase the number of shot-holes is the desirability of bringing down the face in fragments small enough to be lifted without great difficulty. When the rock is completely broken up, the labour, and, consequently, the time of removing it after each blast, are lessened in an important degree. Hence there will be an advantage in placing the shot-holes sufficiently close together to ensure the fracture of the mass between each. These circumstances render it necessary to bore a large number of holes when the work is done by mechanical means. The boring of the additional holes reduces the superiority of machine over hand labour, and the additional quantity of the explosive required augments the cost of the work. To counterbalance these disadvantages, the shot-holes should be bored deep. It has already been pointed out that when a hole is once started with a machine, the rate of progress is immensely superior to that attained in hand boring, and to profit by this advantage, the hole should be continued to as great a depth as practicable. This is sufficiently obvious, since it amounts to increasing the proportion of the whole time consumed that is occupied in actual boring; for as it is in the rapidity of the operation of boring alone that the superiority of machine labour exists, it is plain that the longer the proportion of the time so occupied, the more marked that superiority will be. Thus, by increasing the depth of the holes to the farthest practicable limit, we approximate as much as possible to the condition most favourable to machine boring. The intermediate system, therefore, which takes full advantage of this means, will lead to the best results. To recapitulate the main points of such a system; it should follow the lines of least resistance when that can be conveniently done, and neglect them when the fulfilment of their requirements would occasion a considerable expenditure of time; and to counterbalance the disadvantages of machine boring, it should employ shot-holes of as great a depth as is practicable.

Supposing such a system in use, it now remains to consider the operations of boring, and the subsequent operations of charging, firing, and removing the rock dislodged by the blast. Of the method of executing the boring, little remains to be said. It may, however, be well to direct attention to the necessity of keeping the holes clear of the débris. To ensure this, the bits should be chosen of a form suitable to the nature and the structure of the rock, and the hole kept well supplied with water. When the hole becomes deep, it should be cleared out with a scraper during the time of changing the bit, and in very argillaceous rock it may become necessary sometimes to withdraw the tool, and to remove the accumulation with the scraper. When the débris does not work out freely, its escape may be facilitated by giving a slow motion to the tool, and then suddenly changing to a rapid motion. When several machines are employed, the maximum number that can be applied with advantage is one to the square yard of working face. The absolute number of holes required in any case, will, of course, depend upon the tenacity of the rock and the development of the joint planes, and also, in some degree, by the lines of fracture due to the preceding blast. The same circumstance will determine the distribution of the holes. Leaving minor variations out of account, however, the same distribution will be adhered to throughout the driving.

The manner of distributing the holes over the face of the heading may be varied according to the judgment of the engineer in charge; that is, the general features of the distribution to be adopted may be chosen to suit the requirements of the machines and their supports. Also, it should be noted that one method of distributing the shot-holes will require a less number of them than another. Some examples will be found on Plate IX., where there are represented the Göschenen end of the St. Gothard tunnel; the Airolo end of the same tunnel; the face of a stone drift driven at Marihaye; that of a similar drift at Anzin; and that of a drift of the same character at Ronchamp; the latter three examples being typical of the distribution adopted in the French collieries.

The same mode of unkeying the face is adopted with machine as with hand boring. Generally, two parallel rows of holes, from two to five in a row, are bored in the middle of the face or fore-breast, the rows being from 18 inches to 30 inches, according to the strength of the rock, apart on the surface, and angled so as to be from 9 inches to 15 inches apart at the bottom. These shots unkey the fore-breast; and it is greatly conducive to a successful accomplishment of the operation, to fire these shots simultaneously. Sometimes, when dynamite is used, another method is adopted. A hole is bored horizontally in the centre; at about three inches distant, are bored three other holes at an equal distance apart. These latter are heavily charged with dynamite, the centre hole being left empty. When these charges are fired, the rock between them is crushed, and a large hole made. The lines of fracture of the subsequent shots run into this hole. In this case, it is even more desirable than in the preceding to fire the central shots simultaneously.

In shaft sinking, if the strata are horizontal or nearly so, it is usual to unkey from the centre, as in the heading. But if they be highly inclined, it will be better to unkey from one side of the excavation.

The water which flows into the workings must be collected into one place, both for convenience in raising it, and for the purpose of keeping the surface of the rock clear for the sinkers. The depression caused by the removal of the key serves to collect the water, and, on that account, it is called "the sump." Into this sump, the tub dips, or, when pumps are used, the suction pipe drops. When the strata are highly inclined, the water gravitates towards the dip side of the excavation, and it becomes, therefore, necessary to place the sump in that situation. The unkeying of the rock from this direction is, moreover, favourable to the effect of the shots. In putting in the shot-holes, it is well to avoid, as far as possible, terminating them in, or nearly in, a bedding plane, because when so terminated, the force of the charge expends itself along this plane. The position and the direction of the holes will, however, be determined in some degree by the character of the support used for the drills, and by other conditions of convenience.

Charging and Firing.—The operations of charging the holes and firing the shots demand particular attention when machine labour is employed. It has been pointed out in the foregoing paragraphs that holes bored by machine drills cannot be placed or directed strictly in accordance with the requirements of the lines of least resistance; but that, on the contrary, these requirements can only be approximately complied with, and in some cases must be wholly neglected. To compensate in some degree this defect of machine labour, the strength of the charges should be varied according to the resistance which they will be required to overcome. That is, the principles of blasting described in a former chapter, which cannot be complied with by the borer, should be strictly followed by the blaster in apportioning his charges. By this means, a great saving of the explosive compound may be effected, and that without difficulty or loss of time, if the blaster be intelligent and understand his work. A glance will be sufficient to show what charge a given hole of a known depth will require, and as cartridges of different sizes are ready at hand, no delay is occasioned in making up the charge. The holes in the centre, which are intended to unkey the face, require, of course, the heaviest charge, since the conditions are there most unfavourable to the effects of the explosion. And the more complete is the unkeying resulting from this first explosion, and the more fractured and jointed is the rock surrounding the cavity thus formed, the more may the charges placed behind these unsupported faces be reduced.

As economy of time is, in machine boring, the chief end to be attained, the tamping should be done with dried clay pellets previously prepared. This material gives the greatest resistance, and thereby ensures the maximum of useful effect; and if prepared beforehand, in the manner described in the preceding chapter, the time consumed in tamping will be reduced to a minimum. An abundant supply of such pellets should always be ready at hand. In downward holes, such as are used in shaft sinking, the plastic clay pellet and sand may be employed. This tamping may be put in very rapidly, and, in all but very shallow holes, it is very effective. When it is desired to use sand tamping in horizontal holes, and holes bored in an ascending direction, the sand should be made up in paper cartridges. The tamping employed in the St. Gothard tunnel consisted of sand prepared in this manner. At the Mont Cenis tunnel, an argillaceous earth was similarly prepared in paper cartridges for tamping.

Firing the charges also affords an occasion for the exercise of knowledge and judgment. A skilful determination of the order in which the charges are to be fired will in a great measure compensate the ill effects of badly-placed holes. The firing of a shot leaves the surrounding rock more or less unsupported on certain sides; and it is evident that to profit fully by the existence of these unsupported faces, the succession of explosions must be regulated so that each shall have the advantage of those formed by the preceding shots. This condition can be wholly fulfilled only by simultaneous firing; but when the firing is to take place successively, the condition may be approximated to by regulating the succession according to the indications observed on a careful inspection of the rock. Before firing the charges, the blaster should consider the relative positions of the holes, the stratification and jointing of the rock, the fissures caused by the preceding blast, and any other circumstances that may influence the results. The charges intended to unkey the face will be fired first, and those in the concentric series will be then fired, in the order determined upon, by means of different lengths of fuse. The series will follow each other from the centre outwards. When a large number of shots regularly placed in series have to be fired, a convenient practical means of ensuring the successive explosion of the series, in the case of the whole being lighted simultaneously, consists in bringing the fuses from all the shot-holes together to one point at the centre. This method of regulating the length of the fuses was adopted at the St. Gothard tunnel.

It is obvious that the acceleration of the labour of excavation, which has been effected in so remarkable a degree by the introduction of machine drills and strong explosives, may be still further promoted by the adoption of electricity as the firing agent. The advantages of firing a number of shots simultaneously, some of which have already been pointed out, are great and manifest. In the case of a driving, for example, when all the holes have been bored and charged, and the machines withdrawn, it is clearly desirable to blast down the face as quickly and as effectively as possible. If the whole of the shots can be fired at once, the time is reduced to a minimum, and, consequently, the maximum of progress in a given time is ensured. Electricity affords, indeed, the most convenient, the most effective, and the most safe means of firing blasts. Hofrath Ritter von Pischof, the Austrian Chief Inspector of Railways, in one of his reports, says:—"A greatly increased amount of work and a notable saving of cost are effected when the shots can be so disposed and fired as to mutually aid one another. These results are obtained by employing electricity as the firing agent. The experience which has been gained at the Büchenberg cutting, where electrical firing has been extensively adopted, has shown that, when properly employed, this means allows, in comparison with the ordinary methods, twice the amount of work to be performed in a given time. It is therefore highly desirable to adopt electrical blasting whenever it is a question of economy of time and money."

Removing the dislodged Rock.—As the removal of the rock brought down by the blast consumes a large proportion of the time saved by machine boring, it becomes necessary to provide means for reducing this loss to a minimum. The most important of these means is a suitable provision for the rapid removal of the machine to a place of safety, and a conveniently designed and well-laid tramway, upon which the rock may be quickly run out without confusion and its consequent delay. The number of wagons required to remove a given cube of rock may be readily ascertained, and sufficient provision should be made for the transport of these to "day" in the most rapid succession. The wagons should be of such dimensions as to be capable of being handled without great difficulty; the importance of this condition will be understood when the frequency of derailments is borne in mind. The shovelling up of the rubbish is greatly facilitated by laying iron plates in front of the face to be brought down previously to the firing of the blast. This expedient is often adopted in important drivings. It has also been remarked that the dislodged rock can be more rapidly removed when it exists in small blocks. Thus there will be an advantage in placing the charges and in regulating their strength so as to completely break up the rock. Another matter of importance in the arrangements for the rapid removal of the rock brought down by the blast, is the proportioning of the number of hands employed to the requirements of the case. This number will increase with the size of the blocks to be lifted, the distance to be run over, and the want of suitability in the *matériel* employed.

Division of Labour.—A proper division of labour is greatly conducive to rapid and economical progress. The operations may be divided into three series, namely: boring the shot-holes, charging and firing, and removing the rock dislodged. Each of these series of operations may be performed by different sets of men, and in several instances this division of labour has been adopted. But it does not appear that such a division leads to the most satisfactory results. The work of boring occupies a much longer time than either of the other two series of operations, and hence the distribution of the time is unequal. It has been found that, generally, where all the arrangements have been well considered, the labour of charging the shot-holes, firing the blast, and removing the rock brought down, can be performed in about the same time as that of boring. Thus it would seem to be more conducive to economy of time to divide the men employed into only two sets: one set to bore the holes, the other to perform all the subsequent operations. This division has been adopted in numerous instances with favourable results. Sometimes the whole of the operations have been performed by the same set; but such an arrangement is not to be recommended. The labour of directing the machines is of too distinct and skilled a character to be confounded with that of removing the débris, without a strong reason for such a proceeding, which does not appear to exist. Besides reserving a set of men specially for this portion of the work, it is desirable to keep the same men to the same machine, for in such a case each man gets accustomed to the peculiarities of the machine entrusted to him, and besides conceives a kind of affection for it that leads to careful handling and watchful attention. In addition to the men required for the operations referred to above, smiths will be needed to re-sharpen the bits and to repair the machines. The amount of this labour will obviously depend upon the number of machines employed, and the hardness of the rock to be passed through.

Examples of Drivings.

The St. Gothard Tunnel.—The St. Gothard tunnel is driven in five sections. First, the "heading" is driven at the roof level 6 feet 6 inches wide, and 7 feet high. The position of the holes is shown in the drawings on Plate IX. The number of holes at the Göschenen end is 28, and the depth about 40 inches. The shots are fired by means of safety fuse, the ends of the fuse being brought together at the centre. This arrangement causes the shots to explode in the proper order of succession. At a certain distance back from the face, is the "right enlargement;" this is a widening of the heading to the limits of the tunnel in that direction. Farther back is the "left enlargement," by which the heading is widened to the full width of the tunnel. Still farther back is the first "bench cut," in which one half of the floor is blasted out to the full depth of the tunnel, and behind this again is the second bench cut, in which the remaining half is removed. The boring machines employed are the Dubois-François, the McKean, and the Ferroux. The explosive agent used is dynamite. The rock is a tough granite.

The Hoosac Tunnel.—At the west end of the Hoosac tunnel, the system adopted was the following. First, a centre cut was made by drilling two rows of five or six holes each, about 9 feet apart on the face, and converging to about 3 feet at their lower ends. The depth of these holes was from 9 to 12 feet, according to the hardness of the rock. These holes are numbered from 1 to 11 on Plate X. They were charged with nitro-glycerine, and fired by electricity, Mowbray's frictional machine being used. As soon as the rock had been removed, the next series of fourteen holes, numbered from 12 to 25, were drilled. These holes were then charged and fired simultaneously like those of the first series. When the rock dislodged had been removed, the third series of holes, numbered from 26 to 41, were bored. This series, like the other two, were charged, and fired by electricity. The effect of these three blasts, which were fired within twenty-four hours, was to advance the heading, 9 feet in height by the full width of 24 feet, to the extent of 7 feet 6 inches. The drawings on Plate XI. are: an elevation of the fore-breast, which shows the positions of the shot-holes; a sectional plan, which shows the directions of the first series of holes; a similar plan, showing the directions of the second series of holes, and the centre cut removed; and a sectional plan of the heading after the second series have been fired, showing the direction of the third series of holes.

The operations of taking out the "bench" were carried on at a distance of about 170 yards back from the fore-breast. This was effected by first drilling six holes 7 feet deep; two of these were each about 4 feet from the face of the bench and close to the side of the tunnel, whilst two others were each 4 feet behind these first holes, and the remaining two holes were 8 feet from the face, 8 feet from the sides of the tunnel, and 8 feet from each other. These were fired simultaneously, the result being to lower the bench about 7 feet throughout the full width of the tunnel. At a safe distance beyond this first bench cut, the same operations were carried on by another gang of men, whereby the bench was lowered to the floor of the tunnel, the full area of 24 feet in width by 22 in height being thus completed.. The rock was a moderately tough granite.

The Musconetcong Tunnel.—The heading of the tunnel, shown on Plate XII., like that of the Hoosac, was driven to the full width of the tunnel. It is clear from theoretical considerations, and experience has confirmed the conclusions, that the method of taking, with machine drills, the whole width of the excavation at once conduces to rapidity of advance, and to economy of explosive. In the example under consideration, three tram lines were laid up to the face. The carriages carrying the drills were run upon the two outside lines. These carriages were simply stout frameworks of oak, each having in front three horizontal iron bars, on which the drills were clamped in a way that ensured easy lateral and vertical motion. After the firing of a blast, all hands were set to shovel the dislodged rock into the middle between the machine lines for the purpose of clearing the latter as soon as possible to make way for the machines to be brought up for the next boring. The lines being thus cleared, drilling was recommenced, and the broken rock removed in wagons upon the centre line of rails. The heading being 26 feet wide, there was ample room, and, a convenient system of switching having been adopted, no delay was occasioned by a want of wagons.

The system followed was that of centre cuts, and subsequent squaring up. It consists in first blasting out an entering wedge or "key," about 10 feet deep in this case, in the centre, and afterwards squaring up the sides by several blasts. In the Musconetcong heading, twelve holes were first drilled, as shown in the drawing, and marked C, A being the floor of the heading. These holes were drilled with from $1\frac{1}{2}$-inch to $2\frac{3}{4}$-inch "bits," in two rows of six, 9 feet apart on the face, and angled to meet at the bottom. They were charged with 25 lb. of No. 1 and 50 lb. of No. 2 dynamite, and fired simultaneously by electricity. The No. 1 dynamite was used in the bottom of these centre holes; in all the subsequent blasts in squaring up, No. 2 only was used.

As soon as the cut was out, a second round of holes was started for the first squaring up, as shown in the drawings, where they are numbered 1, 1, 1, 1, &c. In these and in the subsequent rounds, numbered 2, 2, 2, 2, &c., and 3, 3, 3, 3, &c., the resistance to be overcome is, of course, not so great as in the cut. In the first and the second squaring-up rounds, from 50 lb. to 60 lb. of dynamite was used, and, in the third round, this quantity was increased to 80 lb. or 90 lb., the resistance becoming greater as the roof arch falls at the sides. In this third round, there were generally one or two additional roof holes; these are not shown in the drawing, as their position varied, according to the lay of the rock. The top holes in the first round are also intended to bring down any roof not shaken by the cut, and these are therefore angled sharply towards the centre, and bored from 12 feet to 14 feet deep. In the plan, Plate XII., the number 3 indicates the cut holes, and 4, 5, and 6, the squaring-up rounds. The holes of the first squaring round were always drilled about a foot deeper than the cut holes; when blasted, these generally brought out an additional foot of shaken rock at the apex of the cut. The following table shows approximately the number and the depth of the holes required, and the quantity of dynamite used for a linear advance of 10 feet.

The cut holes being 10 feet 6 inches deep, the blast usually brought out about 9 feet full, which, as explained above, was increased to 10 feet in the subsequent rounds. The cross section being about 175 square feet, in an advance of 10 linear feet, there are about 65 cubic yards of rock to be broken; this gives on an average 0·4 lb. of No. 1 and 4 lb. of No. 2 dynamite, and a little over 6 feet of drilling per cubic yard.

	No. of Holes.	Depth of Holes.	Total Depth of Holes.	No. 1.	No. 2.
		ft. in.	ft.	lb.	lb.
Cut	12	10 6	126	25	50
1st square up	8	12 0	96	..	55
2nd "	8	12 0	96	..	55
3rd "	6	12 0	72	..	85
Additional roof holes ..	2	{10 0 8 0}	18	..	..
	36	..	408	25	245

The "bench" was kept from 150 yards to 200 yards back from the face of the heading, to avoid interruptions from the heading blasts, and to allow plenty of room for handling the wagons, and for running back the machines to a safe distance, previously to firing. The system adopted in removing the bench is shown on Plate XII. First, six top holes, from 12 feet to 13 feet deep, were drilled and blasted; their relative positions are shown in the drawings, A being the centre line, B, the sides in the enlargement, B′, the sides of the heading, C, the face of the bench, and 1, 2, 3, 4, 5, 6, the holes. These six holes lifted the greater portion of the rock; what was left was broken by several horizontal holes. These two sets of holes, at the top and at the bottom, gave an average advance of about 9 feet. The following table shows, for that advance, the number of feet drilled, and the quantity of dynamite burned.

	No. of Holes.	Depth of Holes.	Total Depth of Holes.	No. 2 Dynamite.
		ft.	ft.	lb.
Top holes	6	12	72	62
Bottom holes	4	10	40	45
Totals	10	22	112	107

The sectional area of the bench being about 306 square feet, an advance of 9 linear feet gives about 102 cubic yards of rock to be removed. The quantity of dynamite used was therefore 1·05 lb., and the depth of boring 1·1 foot, per cubic yard of rock broken.

Three machines were used at this bench, two on the top and one below. The holes were commenced with 2¾-inch bits, and terminated by 1½-inch bits. The rock was a tough syenite.

CHAPTER VI.

SUBAQUEOUS BLASTING.

Preparation of the Charge.—It is essential to the success of subaqueous blasting operations, that the explosive substance used should be suitable to the conditions under which it is to be applied. This is true of all blasting, but the requirement is frequently overlooked in some of the operations that have to be performed under water. In clearing a wreck for salvage purposes, gunpowder will in most cases act more effectually than either guncotton or dynamite. Also, in many cases, this compound will prove more suitable than the stronger substances in removing obstructions in water-courses. Examples of this will be given hereafter. But when a wreck has to be broken up, when piles, or objects of a similar character, have to be removed, or when rocks have to be blasted, the more violent compounds will be found to accomplish the purpose much more effectively. Generally, it may be stated that when it is required merely to *remove* objects, gunpowder is the most suitable explosive agent to employ; and that when it is required to *break* objects, the nitro-cotton and the nitro-glycerine compounds are the agents whose application is likely to be attended with the greatest degree of success.

When gunpowder is used, means must be adopted to protect it from the water, since a small proportion of moisture is sufficient to lessen, in a very important degree, the force developed, while a large proportion of moisture will destroy altogether its explosive properties. It is no easy matter, under the most favourable circumstances, to keep the water from the charge; but when the depth of water is considerable, it becomes very difficult to attain that object. The pressure of a considerable "head" will force the water through substances that, without a pressure, are sufficiently impervious. At ordinary depths, metal canisters are usually employed to contain gunpowder. Old oil-cans are as good as anything for this purpose. The fuse, whether safety or electric, is passed through the cork, and the latter is luted with some waterproofing composition. The best consists of:

Tallow	1 part.
Rosin	3 parts.
Guttapercha	4 parts.
Swedish pitch	12 parts.

Instead of metal canisters, indiarubber bags are sometimes used. These are, however, more expensive than the oil-cans, and, in many cases, they are scarcely more efficient or suitable. Small charges of gunpowder may be put into short lengths of indiarubber tubing, so as to form a kind of cartridge. But care must be taken to close the ends securely. The best way is to insert a cork, or if that cannot be obtained, a cylindrical piece of wood, and to tie the tubing to this very tightly with twine. The ends should then be dipped into the luting composition described above. Tubing suitable for this purpose is sold under the designation of "blasting tubes." For large blasts, wooden casks are the most suitable receptacle for the charge. The casks should be well tarred, or, if the depth of water be great, laid over with pitch applied very hot. Great care must be taken to protect the aperture through which the safety fuse, or the wire of the electric fuse, passes.

In blasting under water with gunpowder, only the best and strongest qualities of that compound should be used. The extra strong mining powder of the Messrs. Curtis's and Harvey, commercially known as the E.S.M. powder, is, of all, the most suitable. It is also highly conducive to success to detonate the charge. If the charge be not detonated, the enclosing vessel is ruptured when only a small proportion of the number of grains have been ignited, and, consequently, a large proportion of the charge is blown away into the water unburned. Were gunpowder in blasting charges always fired by a detonation, it would compare in its effects far more favourably with the nitro-cotton and the nitro-glycerine compounds than it does under the circumstances attending the common method of firing it.

When gun-cotton is used, the difficulty of waterproofing is much lessened, but not wholly removed. Inasmuch as this compound may be detonated in the wet state, it is not required to take those precautions which are necessary in the case of gunpowder. But, as we have pointed out in a former chapter, the detonation of wet gun-cotton is effected by means of that of a small quantity of the dry substance. This quantity, which is generally employed in the form of a cylinder, and is called the "priming," must be thoroughly protected from the water. For this purpose, indiarubber tubing may be used, or, if the primer be large, indiarubber bags. When the pressure of the water is not great, a very efficient protective covering is obtained by dipping the primer into melted paraffine. Care should be taken to avoid raising the temperature of the paraffine above the degree required to melt it completely. The primer should be placed in contact with the charge, and it is desirable that the latter, when it can be conveniently made to do so, should surround the former.

Charges of gun-cotton for subaqueous blasts are usually made up of discs of a large diameter, or of slabs of a rectangular form. When, however, the charge has to be put into a bore-hole in rock, the common cartridge is employed.

Tonite, or cotton powder, is largely used in subaqueous blasting operations. This substance is always applied in a dry state, and requires, therefore, to be protected from the water. This protection it is however, not difficult to give. Being prepared for use in a very highly compressed state, it does not readily absorb moisture. In this state, it is enclosed in cartridges, which are subsequently dipped into melted paraffine. This is the form and preparation adopted for ordinary use. For application under water, especially when the depth is considerable, additional protection is given. For wreckage purposes, tonite may be obtained in convenient charges, made up in suitable forms, and sufficiently protected.

When dynamite is used, the conditions are similar to those prevailing in the case of gun-cotton. Since nitro-glycerine is unaffected by water, no necessity exists for protecting it from moisture. But when a charge of dynamite is immersed in water, and not contained in a bore-hole, the nitro-glycerine rapidly exudes. The writer once made several ineffectual attempts to explode a charge of dynamite at a depth of 70 fathoms beneath the surface. The cause of failure was found to be this exudation; for subsequent experiments showed that, though the dynamite was in the form of the ordinary parchment paper cartridges, and was contained in a stout canvas bag, the kieselguhr retained hardly a trace of nitro-glycerine when the charge reached the surface from that depth, after being rapidly lowered and raised.

Hence it becomes necessary to enclose dynamite within some fairly impervious substance, to prevent the exudation of the nitro-glycerine. Waxed linen, or fine canvas overlaid with the composition already described, may be used as a protective covering; for blasts in deep water, indiarubber bags and tubing are employed. When the charge is contained in a bore-hole in rock, exudation can hardly occur, and therefore in such cases waterproofing is unnecessary.

For firing subaqueous blasts with safety fuse, only the guttapercha covered kinds are suitable. Great care must be taken to render the junction of the fuse and the detonator water-tight. A stronger detonator is required under water than in dry ground. Electric fuses offer not only a cheaper, but a far more certain and suitable means of firing in water. This means is now very generally employed. When tension currents are used, the insulation must be very good. In all cases, ample power should be possessed by the firing machine or battery.

The shattering class of explosives are very suitable for subaqueous rock blasting. In many cases, their employment renders the boring of shot-holes unnecessary, an advantage of obviously great importance. When detached or projecting masses of rock have to be broken up, it is sufficient to place the charges upon them. Of course, when so applied, larger quantities of the explosive are required; but though the method is wasteful of explosive, it is very economical of labour and time. Even when large undetached masses of rock have to be removed, the same method may often be successfully followed. Suppose a level surface of rock, for example. A few heavy charges judiciously distributed over this surface will blow out craters of a considerable radius, and more or less fracture the rock in their immediate neighbourhood. A few other blasts then fired between these shattered points will break up the intervening solid portions. Sometimes the rock will be disintegrated to a considerable depth, and so broken up generally that it may be removed by dredging. By proceeding in this way, the whole of the rock may often be removed without any labour of boring.

But when the rock is too tough to be removed in this way, recourse must be had to boring, though even when boring is necessary, an occasional "loose" shot may be found to be very efficacious.

Boring under Water.—The percussive drills, one of which, the Darlington, was described in a former chapter, may be used effectively under water. Compressed air is used as the motor fluid. The tripod stand, having its legs weighted to give it stability, is generally the most suitable support. These drills need the immediate attention of a diver. Sometimes the boring is carried on by hand from the deck of a vessel or from a raft provided for the purpose. The following description will give a general notion of the operations involved in subaqueous boring :—

The working vessel having been moored over the rock by means of mooring-lines attached to buoys placed about 50 yards from each quarter of the vessel, the diver descends and selects the most suitable position for the blast; he then signals, by a certain number of pulls upon his signal line, to have the drill and stand lowered to him. This being quickly done by means of a steam derrick, he guides the drill-stand to its place, and finally fixes it in position by means of its adjustable legs. This being done, he signals for air to commence drilling.

It has been found that the drill can be worked in a rapid current as well as in slack water. This allows the operations of drilling and blasting, by a proper division of time and labour, to be conducted in an extremely rapid tidal current, so that the principal work of the diver, in inserting charges for blasting and slinging stone, may be done near the periods of slack water, while the drilling may be advantageously continued during the period of rapid flow. In a rapid current, the stoppage of the drill for the purpose of "spooning out" the hole becomes unnecessary, as the motion of the drill works up the débris to the mouth of the hole, whence it is sucked out and carried off by the current in a dark stream, like the smoke from the funnel of a locomotive. In a sluggish current, or during slack water, the hose of the air-pump is sometimes introduced, and air forced into the bore-hole to create a current of water, by which means the hole is cleared more thoroughly than by the most careful "spooning out."

As soon as the hole is drilled to the required depth, the drill is stopped; the diver then fastens the derrick chain, which is lowered to him for the purpose, to the drill-stand, and signals to hoist away, whereupon the machine is quickly hoisted on deck.

After having examined the hole and cleared away any débris remaining at the bottom, the diver comes to the surface, and taking in his hand the charge contained in a water-tight cartridge, and provided with its electric fuse to which a sufficient length of insulated wire is attached, returns with it, and inserts it into the drill hole, carefully pressing it to the bottom with a rod. The tamping, if any is used, is then inserted above the cartridge, and the diver comes up.

The working vessel having been quickly hauled by the mooring-lines to a safe distance by means of capstans worked, whenever practicable, by the steam-engine, the wires are attached to the machine, and at the signal " all ready " the charge is fired.

The working vessel is then hauled back to her position, and as soon as the water becomes sufficiently cleared of the dark muddy matter stirred up by the blast, to enable the diver to see in it, he descends and examines the result.

If the blast has been effective, he signals for the stone chains to be lowered to him; which being done, he proceeds to sling the large pieces of broken rock, one after another, as they are hoisted up and deposited on deck. All the pieces large enough to sling having been thus removed, he signals for the tub and shovel, and upon their being lowered to him, proceeds to shovel into the tub the small fragments, and to have them hoisted up and piled on deck, until the surface of the rock is sufficiently cleared to place the drill for a new blast.

Submarine Rocks.—The following brief account of the removal of the "Tower" and the "Corwin" Rocks from the Narrows, at the entrance of Boston Harbour, U.S., from the pen of J. G. Foster, is instructive as illustrating the method of procedure in submarine blasting, and as showing the unfitness, for work of that character, of the slow-burning explosives:—

"Tower Rock," being the smaller of the two, was selected as the one to be first removed. Its horizontal dimensions being only 50 by 26 feet, it was estimated that one large central charge surrounded by five or six others, all in large and deep drill-holes, would be able to rend the rock into pieces.

The working vessel, the sloop "Hamilton," of 70 tons, was moored over this rock on the 30th of July, 1867, and the new submarine drilling machine, designed for this work, by Mr. Townsend, the contractor, was placed in position and tried.

Several imperfections were found at the first trial, which prevented its efficient working. While these were being remedied, a trial was made of surface blasts, placed in and around the rock in the positions most favourable to their action. These proved to be entirely without effect. No seams or breaks were made by them in the smooth surface of the rock.

As soon as the submarine drilling machine was perfected, it was put in operation, and successfully worked. The central and the surrounding holes were drilled to depths varying from 2 to 8 feet, each hole being $3\frac{1}{2}$ inches in diameter. These were well charged with black blasting powder, and tamped with sand. In some holes, the charges produced no visible effect, the tamping being blown out like the charge from a cannon. In others, a crater was formed, but with a radius only about one-half the line of least resistance. The holes that were intact were then deepened, and new ones drilled; these were charged with Dupont's sporting powder. The result was much better, but not what was desired. The pressure of the water, from 23 to 33 feet in depth, seemed to diminish largely the ordinary explosive effect of gunpowder upon rock, as seen in blasts in the open air.

Trial was then made of the patent safety blasting powder, manufactured by the Oriental Company of Boston, the proportions of the ingredients having been modified to increase its strength for this especial use. This produced the desired effect. The rock was rent in pieces; and by drilling additional holes and continuing large charges of the powder, the rock was finally reduced to the required depth.

To smooth off its upper surface and break down the sharp projecting points, large surface charges of sporting powder were employed. These accomplished the result to a limited extent, but not completely. A large 15-inch shell was then placed in a crevice near the centre of the rock and fired. Its explosion swept the rock completely, breaking down and levelling the projecting points.

The work upon this rock occupied eight weeks. In that time, 80 tons of stone had been blasted out, hoisted up, and deposited on shore, attaining the required depth of 23 feet at mean low water. About 70 tons of small fragments were suffered to remain on the bottom around the rock, where they had been thrown by the blasts, and where they could do no harm.

The cost per ton of the quantity hoisted up and deposited on shore was 64·93 dollars, no account being taken of the quantity blown, in small fragments, into deep water.

"Tower Rock" having been entirely removed to the required depth, the moorings of the working vessel were at once removed to "Corwin Rock," and work commenced upon it on the 1st of October, 1867. This rock was found to be much more difficult to blast, on account of its extremely tortuous lamination, its great toughness, and the presence of a great number of iron pyrites.

Surface blasts were also tried upon this rock at the outset, in hopes that, by being placed in the most favourable positions between the sharp ridges of the rock, they might break them down. These, however, like those upon Tower Rock, entirely failed to produce any noticeable effect, even when they contained four and five hundred pounds of the best sporting powder. The drilling machine was therefore called into requisition as before, and used continuously till the completion of the work.

On account of the extent of this rock, a different plan of operations for its removal was adopted. One side of the rock most favourable for blasting was selected, and a row of holes drilled parallel to the edge, and at a distance from it equal to the depth of the holes, which was taken to extend 1 foot below the required level, 23 feet at mean low tide. After blasting out these holes, a new line of holes was drilled parallel to the former line, or to the "face" left by the blasts, and these also were blasted out; then a third line, and so on, progressing regularly across the rock, continually blasting it off in parallel blocks, extending downward a little below the depth required.

The advantages of this mode of operation were that it enabled the blasts to act laterally, in which direction they were the most powerful; and the rock was left, after each series of blasts, with a nearly vertical side, or "face," in which the presence of seams could be more readily detected, and the character of the strata observed, so that the most favourable positions could be selected for the next blasts.

Sometimes the craters, following the strata, ran under, or left an overhanging "face," in which case a large charge placed under its projecting edge, usually had the effect of throwing off the overhanging portion, and sometimes of dislodging large masses.

After the rock had been in this way blasted entirely across, and to the general depth required, a careful survey was made, the soundings being taken in lines from 5 to 10 feet apart, and at right angles to each other, the lower end of the sounding pole being placed by the diver alternately upon the highest and the lowest points.

This survey showed that although more than the required depth had been generally attained, yet many points projected above this level by distances varying from 2 to 14 inches.

To remove these, large surface charges were again tried, but with the same ineffective result. Their only effect was to pile up the sand and small fragments of stone into irregular windrows on the surface of the rock. Small holes had, therefore, to be drilled at each of these points to blast them off. This occupied much more time than could reasonably have been expected; so that it was not until two months' labour had been expended, that all the points were finally reduced to the required level.

Obstructions in Water-courses.—The removal of obstructions from water-courses often leads to much subaqueous blasting. Trees that have fallen into the stream are most effectively broken up by charges of gunpowder fired by a detonation. The success of the operation will, however, be greatly dependent upon the judicious placing of the charges. Brickwork may also be very effectively dealt with by charges of gunpowder. But stone masonry and blocks of rock may be more effectively broken up by gun-cotton, tonite, or dynamite. For work of this character, electrical firing offers great advantages, for, besides its convenience, it allows of several charges being exploded simultaneously, a condition that is always favourable, and in many cases essential, to success.

The following highly interesting and instructive account of the removal by blasting of some obstructions in certain rivers in India is given by Lieut. A. O. Green, R.E.

He, in company with some assistants, left Calcutta for Maldah on the 8th of April, 1874, where they commenced work on the following day upon the wreck of a large county boat, which lay on the top of a tree in mid-stream, as shown in

Fig. 51. Soundings were taken over and around this tree, which was found to be about 3 feet 6 inches in diameter at its base. The gunpowder intended to be used in these operations not having arrived, three 5-lb. charges of gun-cotton were made up; it was thought that under the 15-feet head of water, these would have been sufficient to break the tree in half. The gun-cotton was in the form of compressed discs, $2\frac{1}{2}$ inches in diameter, and 2 inches thick, each disc weighing about 5 ounces. These discs were filled into a tin cylinder to within about 4 inches of the top. An electric fuse, with wires attached, having been securely pushed into the hole in the centre of the top disc, the empty space above was filled up, with first a layer of sawdust, and then a layer of plastic clay, well rammed. The whole was then painted over, and the upper end tied up in a covering of waxed cloth, the holes through which the fuse wires passed being carefully luted. The charge, thus made up, is shown in section in

FIG. 51.

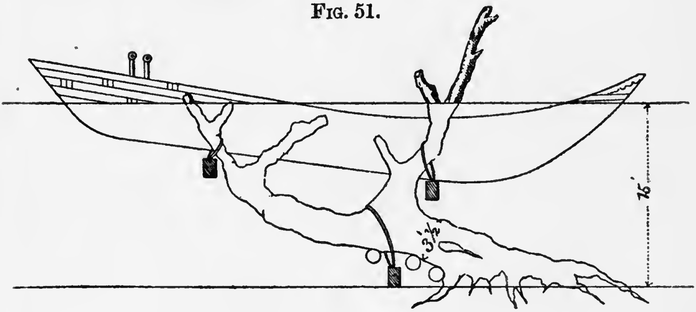
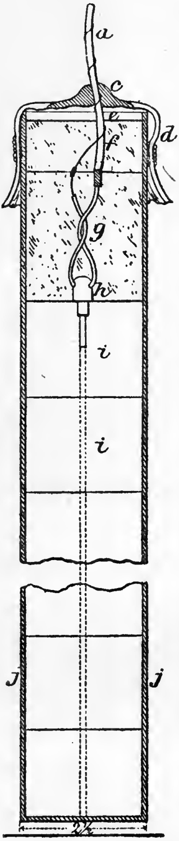


Fig. 52. It was fired by means of a dynamo-electric machine.

The first charge produced but little effect; a second failed from the case not being water-tight; a third charge was more effective, as it lifted the tree and the boat partially out of the water. The positions of these gun-cotton charges are indicated by circles on the figure. The next day, two charges of gunpowder, of about 70 lb. each, were placed under the boat, these charges being lashed on to the snag by the divers. These charges consisted simply of common oil-tins, carefully cleaned and painted over with red-lead paint. The bunghole was closed by a wooden plug, bored through to allow the fuse wires to pass. This plug, after being inserted, was coated over with a waterproofing compound. The effect of the two charges was to completely demolish the boat. Another charge of 50 lb. removed the tree underneath. The positions of these gunpowder charges are indicated by squares in Fig. 51.

Fig. 52.



The next obstruction met with was a sand bank caused by a boat which had broken in half and then sunk. The sand nearly covered the boat, so that there was little else to operate upon. A charge of 80 lb. (one large charge being considered preferable to two or three small ones in getting rid of the sand), placed close to the part of the boat that was visible, made a considerable crater, and a second charge of 80 lb. was placed in a much more favourable position, as nearly all the boat was removed except portions of the bow and stern, which required two separate charges of 50 lb. each before they disappeared. In half an hour, the whole of the sand bank had been washed away by the stream, and there was from 3 to 4 feet of water over the spot where before the sand was high and dry out of the water. The removal of this obstruction was dangerous, owing to the nearness of the boat to the surface, the consequent small resistance offered to the projection of its pieces through the air, and the largeness of the charges used. Had, however, small charges been used, it is more than probable that the small craters made by them would have become too quickly filled up again to have been of any good in facilitating the placing in position of subsequent ones.

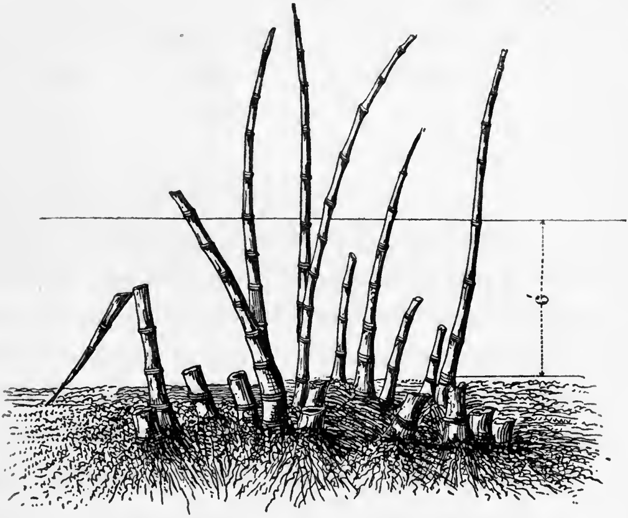
The following day, a large mango tree, about 4 feet 6 inches in diameter, was destroyed by two 50-lb. charges, which broke it up into three pieces, easily removable ashore.

A few days later, a large trunk of a tree, about 3 feet in diameter, was removed with two 50-lb. charges; but the depth of water over it was so small that a large portion of the trunk was thrown a considerable distance on shore. The next day a large tree which had formed a sand bank was very successfully removed by a charge of 50 lb. placed among the roots, it being considered that a smaller charge than 50 lb. would not have effected the purpose. Opposite to Kásimpore, a boat was removed with a charge of 50 lb. placed in the centre up-stream, which entirely demolished it, the pieces being all dragged ashore. At Mootyá, a large cotton tree, the wood of which is extremely tough, was found with many large branches projecting out of the water. A charge of 70 lb. tied under the tree at the springing of the branches effectually broke it up, and the pieces were all hauled to land. Three miles farther down the river, an attempt was made to destroy another large cotton tree with a similar charge, but it only broke it into three pieces, and two more charges of 50 lb. each were necessary to clear it away effectually. This tree was, if anything, slightly larger than the last, i. e. from 3 to 4 feet in diameter, and there was less water over it.

Farther on, the party came across a collection of three or four trees, with their branches interlaced, lying on a sand bank near Alumpore Dáldah; these were sufficiently broken up by a 70-lb. charge to make them easy of removal by coolie labour. Opposite to the village, another awkward snag, in the shape of a large tree sticking up in 30 feet of water, was destroyed by tying a 70-lb. charge at its base. A charge of 50 lb. of powder under this head of water, or even a smaller amount, might have been sufficient, but as the work had to be done quickly, not much account was taken of a few pounds of powder more or less, provided the object was attained. At Gomashtapore, a large tree, branches and all, was found in 25 feet of water, lying in the channel under the bank. The current here was considerable, and some difficulty was experienced in placing the charges. One charge of 70 lb. broke the tree in half; another of 50 lb. at the springing of the branches broke them up; and another of the same weight got rid of the roots. Below Gomashtapore, a large mango tree was demolished with 60 lb. of powder. A short distance farther on, a bad bamboo snag was met with. These bamboo snags, which were merely the roots of the bamboos with perhaps a dozen or so whole ones left, gave much trouble. Fig. 53 gives an idea of what these snags are like. It was found impossible to place a charge underneath this one, so an opening was prized between the bamboos, and a charge of 70 lb. rammed down pretty well into the middle. This cleared the whole of it away and opened the channel.

At Chandpore, at a re-entering angle of the river and in a place peculiarly dangerous to navigation during the rains, was an enormous banyan tree (*Ficus Indica*), the main trunk of which, to judge from the branches, must have been at least from 12 to 15 feet in diameter. An approximate measurement was made with a pole, but any such measurement can only have been a very rough one.

Fig. 53.



The trunk was lying in deep water, but the branches, more like an accumulation of large trees, were lying stretched out for a considerable distance over the bank, covering an area of more than 80 square feet. A charge of 200 lb. of powder was made up in an indiarubber bag, and placed by the divers in about 28 feet of water, well under the trunk of the tree. The effect of this was to split the trunk up into several pieces, each of which subsequently required separate removal. A 70-lb. charge was next fired under two of the largest pieces in 18 feet of water, and this broke them up completely. Having now run out of all the cases for powder, three charges of gun-cotton, similar to the first, were made up, and fired separately, each placed under a good thick branch, about 8 feet in girth. The effect of all three was prodigious; seemingly greater than that of the 70 lb. of gunpowder. As there were no more cases left, and time was precious, some common earthenware ghurrahs were obtained from the village as a makeshift. These held about 20 lb. of powder; the fuse was placed in the centre in a disc of gun-cotton, and the neck was closed up with damp earth, white-lead paint, &c., just in the same way as the gun-cotton charges had been. A rope for lashing them to the obstacle was securely fastened round the neck, and the fuse wires were tied under this lashing, leaving a small loop towards the fuse free, so as to avoid any chance of a strain being brought on the fuse in lowering the charge. Figs. 54 and 55 show the arrangement of this charge. The

Fig. 54.

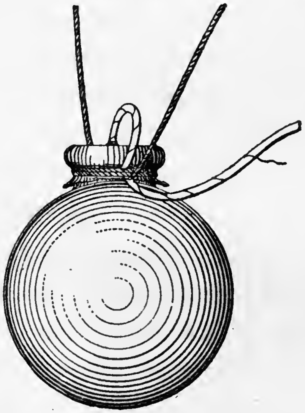
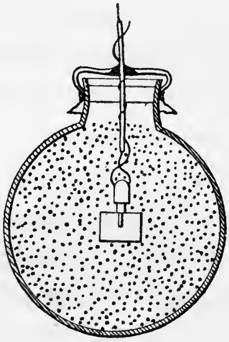


Fig. 55.



first one tried had but little effect when placed under a branch of the tree in deep water, and it was accordingly determined to wait for cases from Calcutta; but after waiting five days without their appearing, three more of these charges were tried, and this time with very excellent results. They were indeed so satisfactory, that the same evening four more were made up and fired. The first under a mango tree a little farther down the river. This broke it in half, throwing one part high and dry on shore, and the other into deep water. The other three were fired under the remaining branches of the banyan tree with very good effect, cutting them away.

It is more than probable, observes Lieut. Green, that the good results obtained with all these ghurrah charges were entirely due to the gun-cotton disc inside causing the gunpowder itself to detonate, so that the thinness of the envelope was of little moment in determining the force of the explosion.

The tin cases having arrived, the rest of the powder was made up into five charges of 48 lb. and three ghurrah charges of 20 lb each. About four miles farther down the river, there was an old peepul tree lying in mid-channel, with several of the branches above water. Two tins, one placed under the springing of the branches and the other under the roots, blew away the lower branches on which the tree was resting, and it sank slightly in the water. A ghurrah was next fired under the trunk with splendid results, the tree disappearing entirely except one branch, which required another small charge to remove it. The trunk of this tree was nearly 8 feet in diameter, but of soft stringy wood.

On returning to camp, a small charge of 2 lb. of gun-cotton was made up in a section of bamboo, and used against the banyan tree with very good effect, and a ghurrah charge demolished the last branch but one. The next day $1\frac{1}{2}$ lb. of gun-cotton in a piece of bamboo finished the last of this enormous tree.

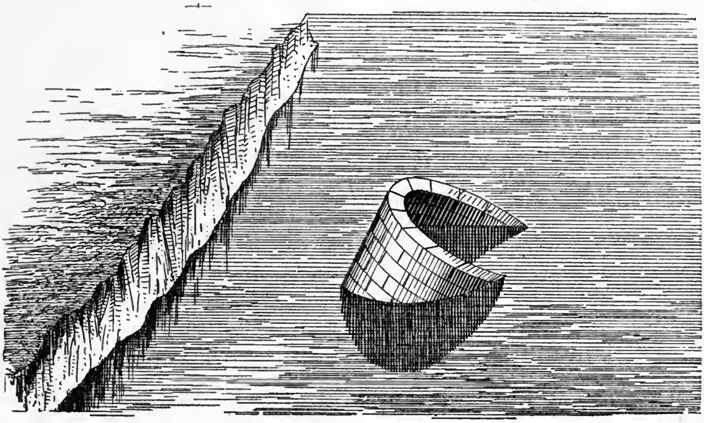
After clearing away several more trees, the foundations of an old factory, which had slipped into the stream, were removed by introducing two charges of $1\frac{1}{2}$ lb. of gun-cotton, in the ends of two bamboos, well into the crevices of the masonry under the water.

Another obstruction consisted of a row of old piles, about 15 inches square, stretching across the river below the surface of the water. Six of the most dangerous of these were removed from the dry season channel with ghurrah charges tied to the foot of the piles.

An old well that had fallen bodily into the water was afterwards met with. The position of this well is shown in Fig. 56. A charge of 4 lb. of gun-cotton completely destroyed it.

Near Azimgunge, the trunk of a very large peepul tree was found sunk in deep water. It was so large that it was thought necessary to place a 100-lb. charge underneath it; this charge broke it up completely, but two small charges of 20 lb. each were subsequently required to remove the pieces.

FIG. 56.



Later on, a well, similar to the one previously destroyed, was met with. The brickwork was remarkably good and about 3 feet thick, and the mortar was excellent. One charge of 4 lb. of guncotton broke it up into large pieces; but it took another similar charge, and two charges of 20 lb. of gunpowder to destroy it completely. On the same day, two trees were removed with ghurrah charges, which had been used throughout, for small charges, with unvarying success.

At a place called Farrashdangah, there was a very bad obstruction in the river, caused by the remains of an old bathing ghat and bridge having been cut out from the bank by the water getting underneath the masonry. Both were projecting about 3 feet above the water, and in the rainy season they formed the centre of a very nasty and dangerous whirlpool, in which many boats had, according to the Executive Engineer of the Nuddea Rivers Division, been lost. There was an immense mass of masonry, but no means of getting a charge placed underneath it; so a charge of 100 lb. of powder was placed close alongside it in about 15 feet of water. This shunted the mass bodily over and underneath the water. Two 50-lb. charges were next placed underneath the mass, and these shattered it all up, except one piece, which was got rid of with a fourth charge of 20 lb. placed well underneath it. The Executive Engineer wishing that the wing-wall of the bridge, which was on dry land during the dry season, might be removed as well, a small hole was made at the foot of the visible portion of the brickwork, and a charge of 2 lb. of gun-cotton was introduced into this, and fired with only a tolerable effect, the brickwork being cracked for a distance of 3 or 4 feet from the centre of the charge. A hole was next dug down about 5 feet at one side of the wing-wall, and a charge of 4 lb. of gun-cotton well tamped was fired. The tamping was blown out, and the wall foundations cracked a good deal. The excavation was now deepened to 6 feet, and a hole made under the brickwork big enough to contain a 100-lb. charge. It was then well tamped up and fired. Its effect was excellent. All the brickwork of the wing-wall was got rid of, and a crater about 30 feet in width at the top blown out in the point of the bank that was required to be removed, and which was one of the chief causes of the whirlpool, so that the next rise of the river was sure to carry it all away. The following day an old pucka ghat opposite to Berhampore was entirely broken up with three 20-lb. charges, and an enormous quantity of old bricks were thrown into the river.

The last operation undertaken consisted in the blowing up of a very large ghat opposite to the Nawáb of Moorshedabád's palaces. The river during successive rains had cut into and underneath the steps of the ghat, bringing down large masses of it into the river, where they formed most dangerous obstacles to navigation. The work was necessarily carried out in a very rough way, for want of the proper tools. Deep excavations were made under the three largest masses of masonry, at about 25 feet apart, and into these were introduced three 50-lb. and one 20-lb. charges of powder. These charges were well tamped, connected up in divided circuit, and fired simultaneously. All the masonry was broken up completely, so as to be easily removable afterwards by coolie labour, which was all that was required.

The conclusions to be drawn from the foregoing notes are, that large trees lying in shallow water require charges of 50 lb. of gunpowder and upwards for their effectual removal; but that where there is plenty of water, and the trees are not very large, 20 lb. is sufficient.

For these small charges, it has been seen that the common earthenware ghurrah answers admirably, and under similar circumstances it would undoubtedly be advantageous to use them, as they are inexpensive, and obtainable in nearly every Indian village.

The charges used might, in many cases, at first have been no doubt made smaller with advantage, both for safety and economy; but as speed was the great object, these were not so much thought of.

For the removal of masonry under water, it is not necessary to place the charge underneath the mass, which is often impossible; a large charge alongside it being generally quite sufficient to break it up pretty effectually where there is sufficient head of water. Smaller charges can of course be easily used afterwards, whenever required, and for these small charges, gun-cotton is very effective, as it can be easily introduced, in the end of a bamboo, into holes and crevices where it would be impossible to get any but the smallest charges of gunpowder.

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LONDON: PRINTED BY WM. CLOWES AND SONS, STAMFORD STREET AND CHARING CROSS.

Plate 1.

SET OF COAL BLASTING GEAR.

Fig. 1.

Fig. 2.

Fig. 4.

Fig. 5.

Fig. 3.

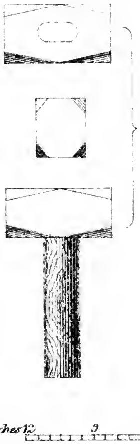

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Plate II.

SET OF SINGLE HAND STONE BLASTING GEAR.

Fig. 6.

Fig. 7.

Fig. 9.

Fig. 10

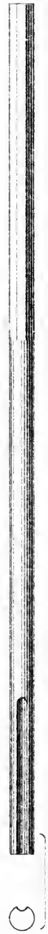
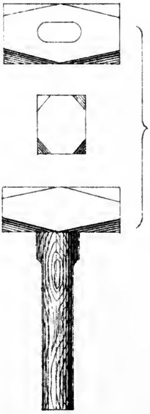
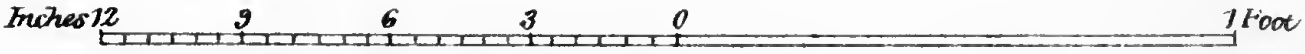


Fig. 11

Fig. 8.





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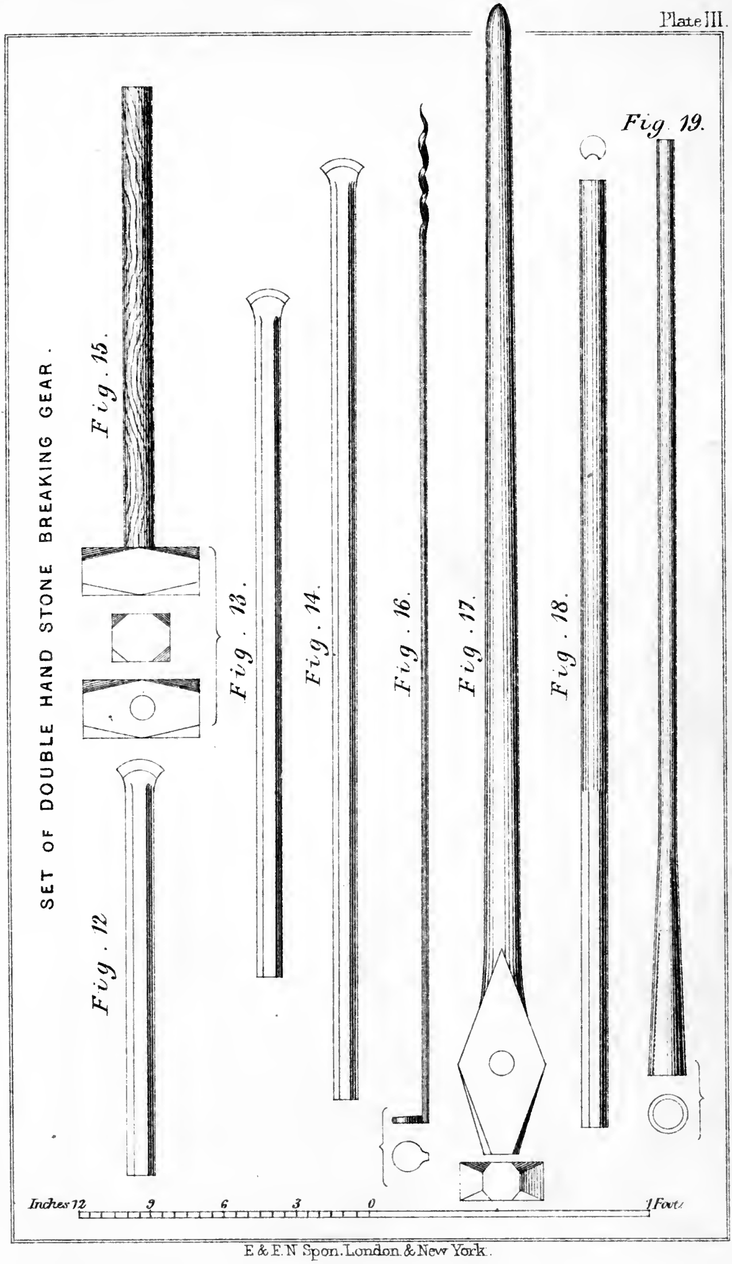
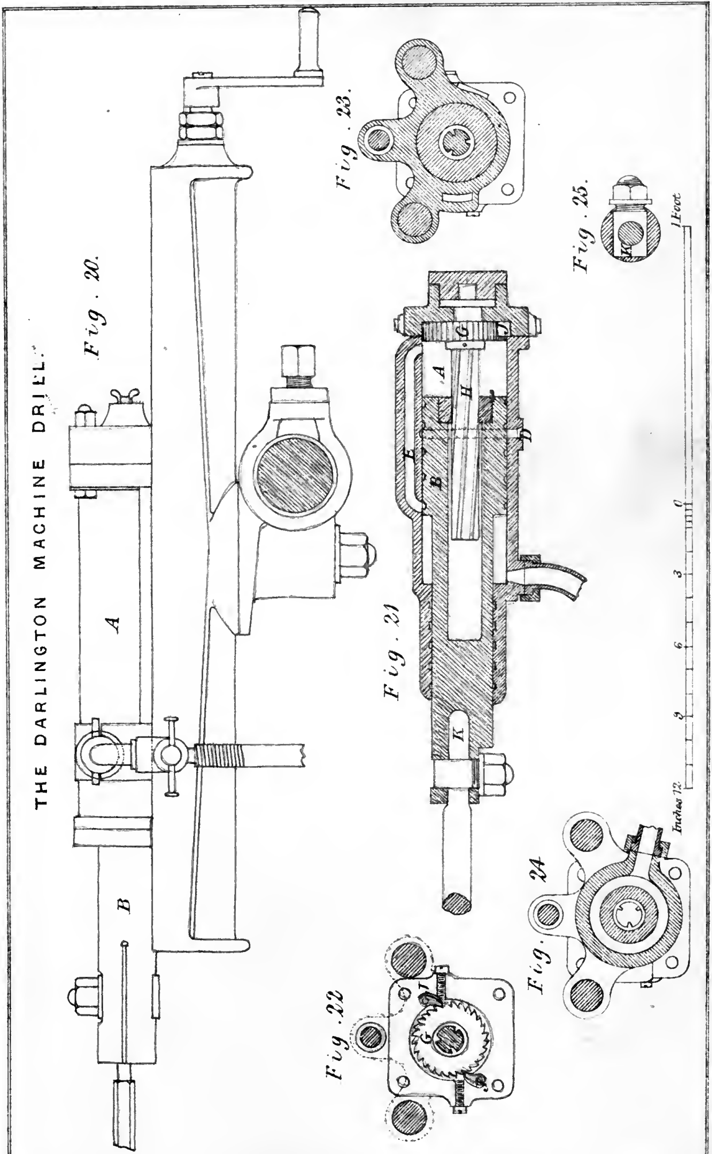
SET OF DOUBLE HAND STONE BREAKING GEAR.



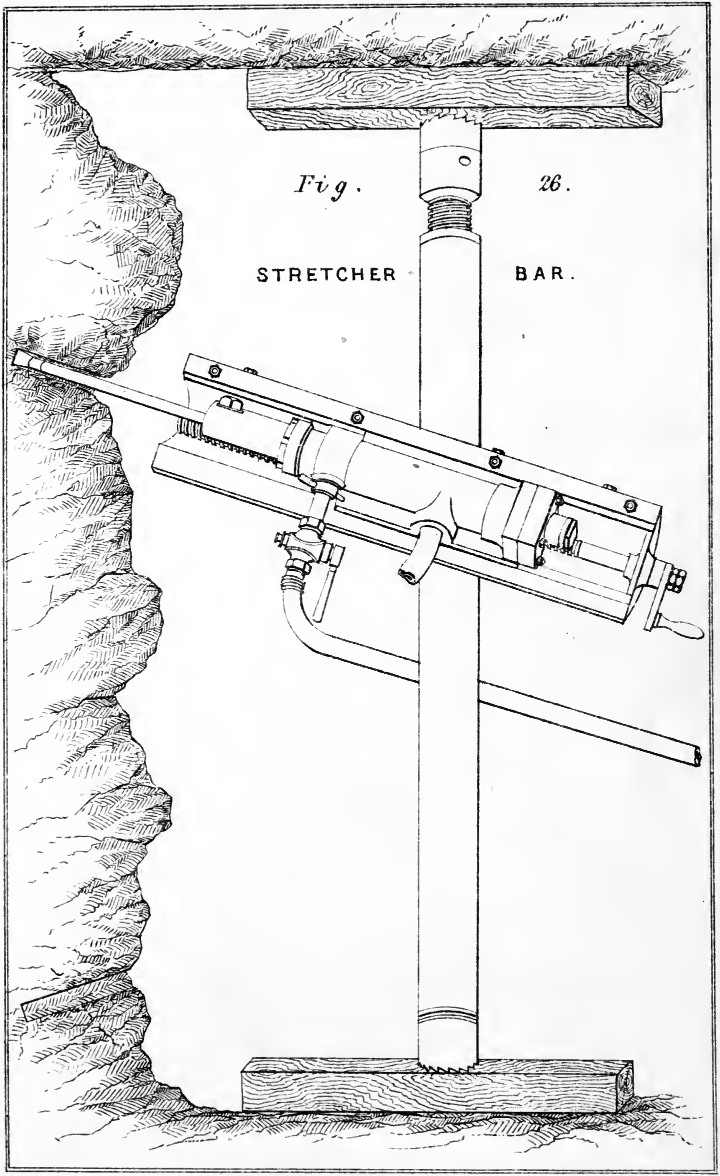
E & F. N. Spon. London. & New York.

Plate IV

THE DARLINGTON MACHINE DRILL.



E & F.N. Spon. London & New York.



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MACHINE DRILL SUPPORTS.

Fig. 27.

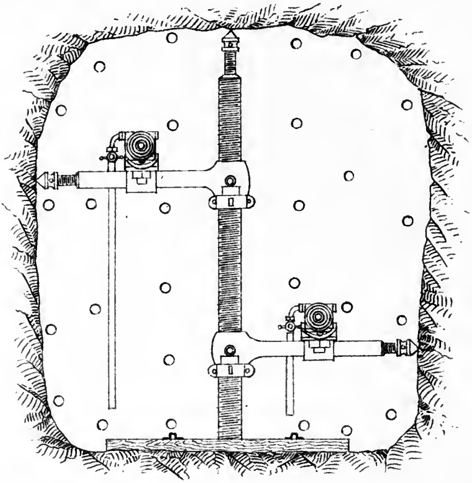
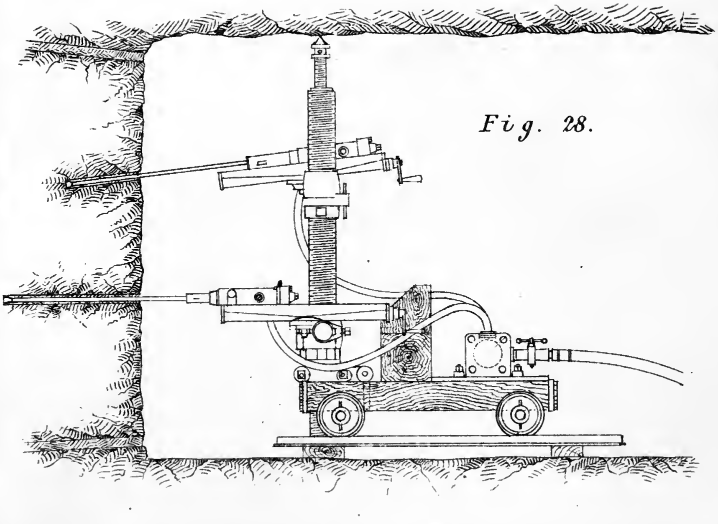


Fig. 28.



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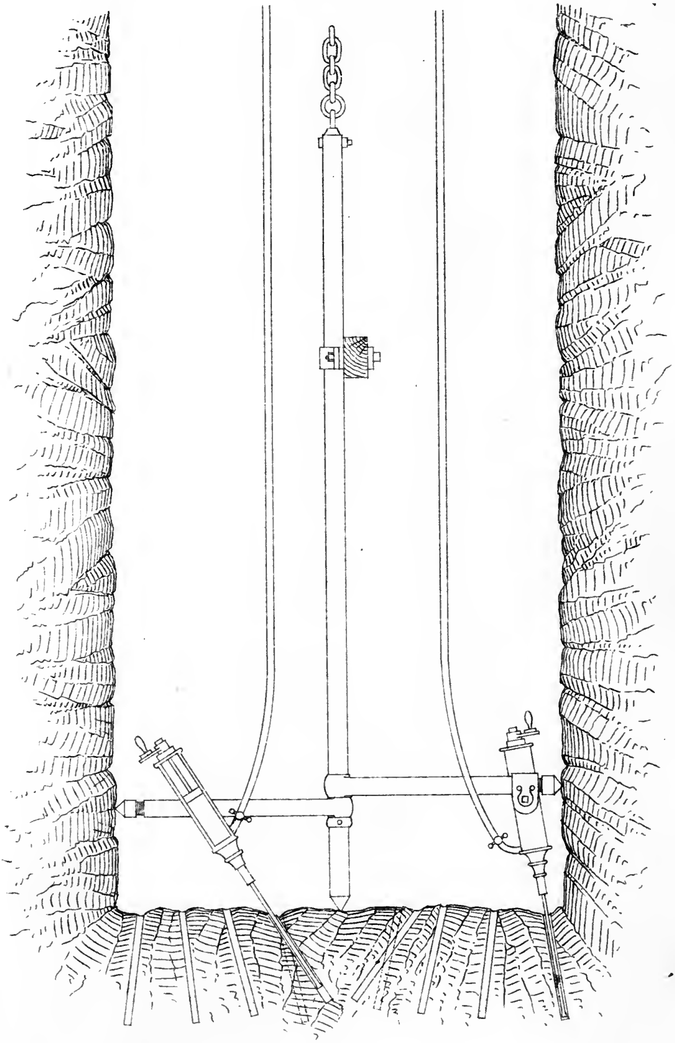
MACHINE DRILL SUPPORT.

Fig. 29.



E & F. N. Spon. London & New York.

Plate VIII

DUBOIS-FRANÇOIS MACHINE DRILL CARRIAGE.

Fig. 30. Elevation.

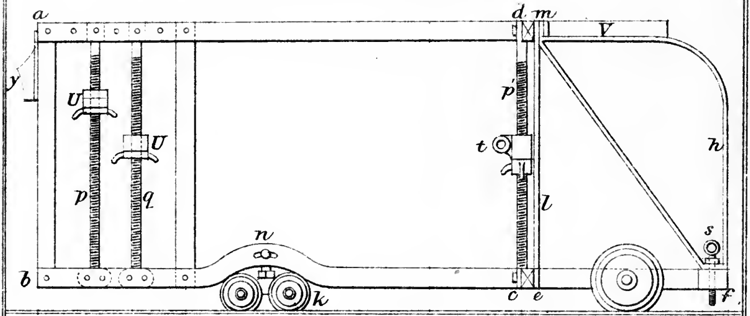


Fig. 31. Plan.

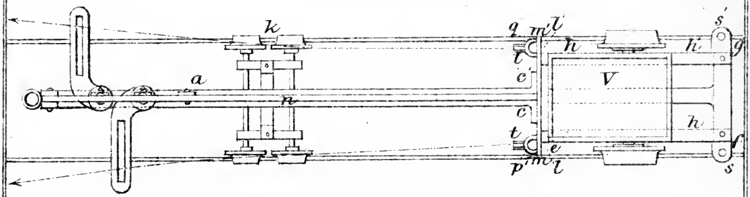


Fig 32.

Raising and lowering Screw.

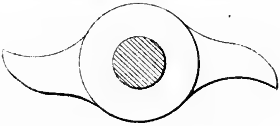


Fig. 33.

Back support for the Drill.

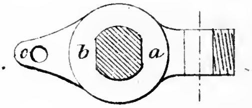


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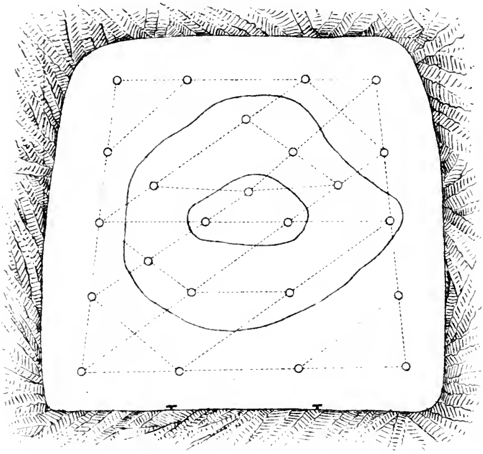
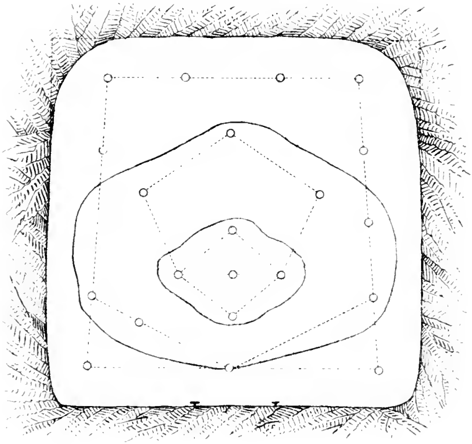
Plate IX

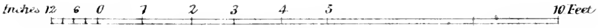
ST. GOTHARD TUNNEL.

Göschenen End.



Airolo End.





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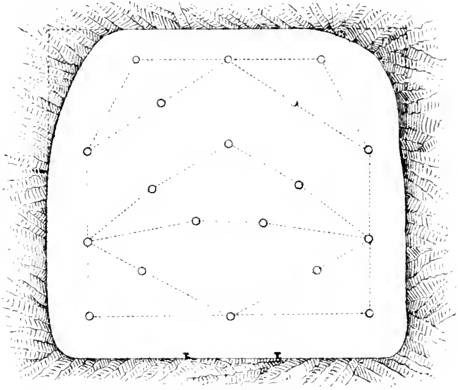
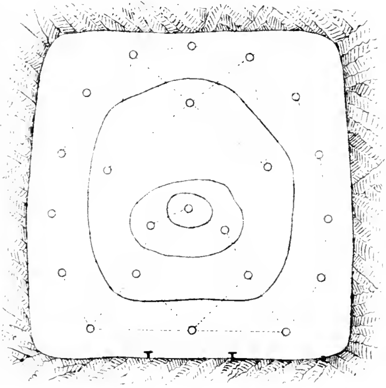
EXAMPLES OF HEADINGS.

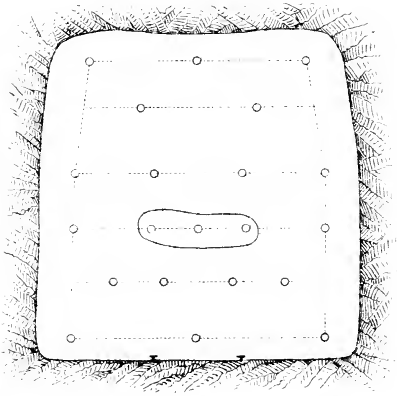
Heading, Marihaye.



Heading, Anzin.



Heading Ronchamp



HOOSAC TUNNEL — *West End.*

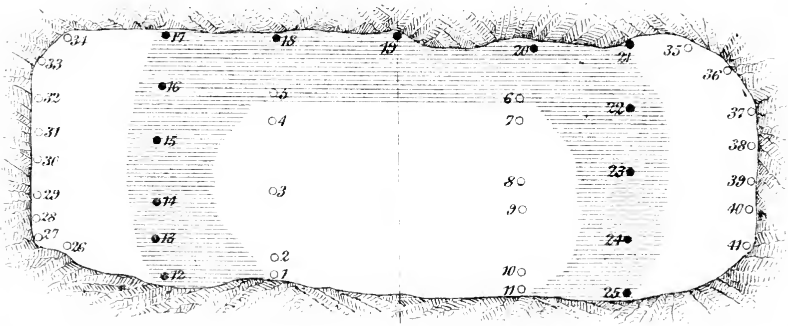


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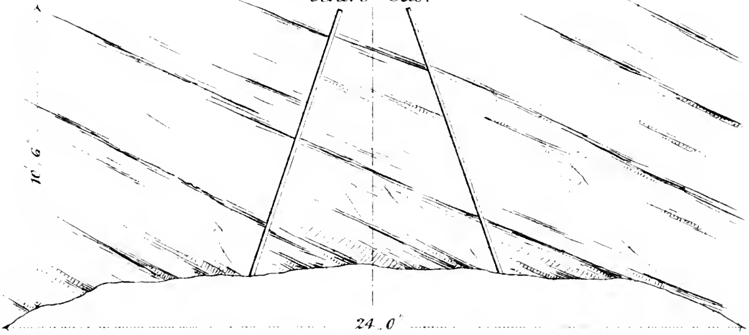
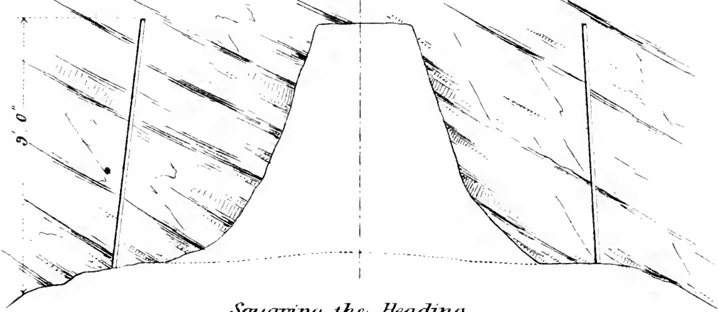
Plate XI.

HOOSAC TUNNEL.

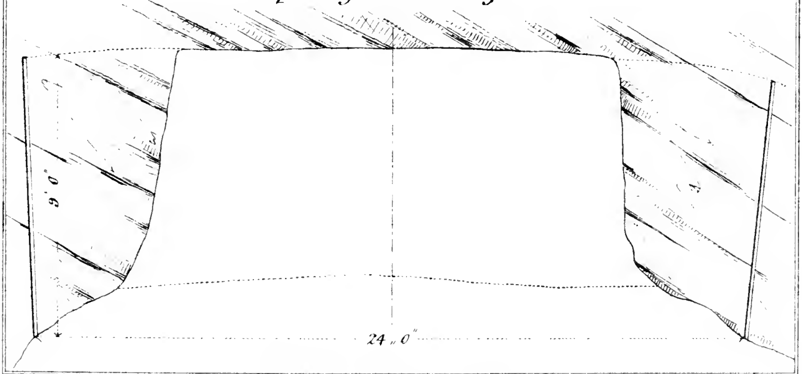
Centre Cut.



Side Cuts.



Squaring the Heading.



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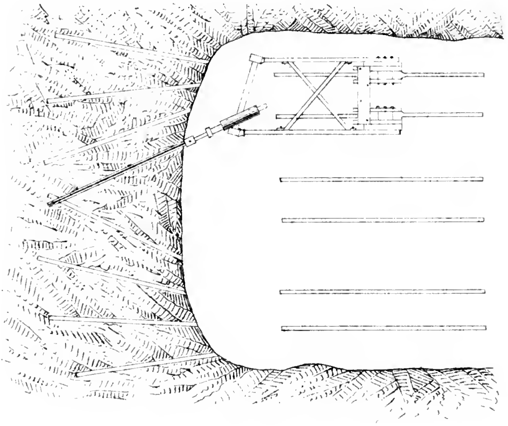
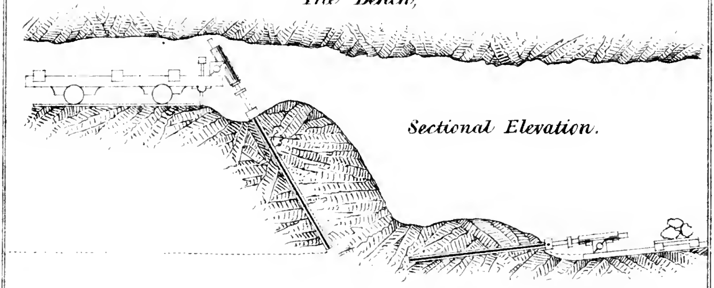
MUSCONETCONG TUNNEL.

The Heading; Plan.

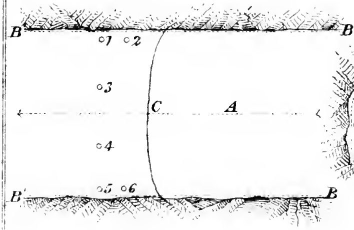


The Bench,

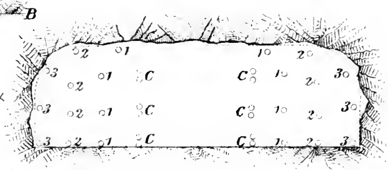


Sectional Elevation.

The Bench,- Plan.



The Heading,



Elevation.

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