BLASTING.

BLASTING:

A HANDBOOK FOR THE USE OF ENGINEERS AND OTHERS ENGAGED IN MINING, TUNNELLING, QUARRYING, ETC.

BY

OSCAR GUTTMANN, M.INST.C.E., F.I.C., F.C.S.,
MEMBER OF THE SOCIETIES OF CIVIL ENGINEERS AND ARCHITECTS OF VIENNA AND BUDAPEST, CORRESPONDING MEMBER OF THE IMP. ROY. GEOLOGICAL INSTITUTION OF AUSTRIA, ETC.

SECOND EDITION.

WITH NUMEROUS ILLUSTRATIONS.

LONDON:
CHARLES GRIFFIN AND COMPANY, LIMITED,
EXETER STREET, STRAND.
1906.

PREFACE TO THE FIRST EDITION.

During the many years in which I have been actively engaged in the manufacture of explosives and in mining work, I have frequently been asked to write a short handbook for the assistance of practical men who have to conduct blasting operations in mining and civil engineering work.

Since the older methods of Blasting have been altered by the introduction of dynamite, the descriptions of the various operations conducted throughout the world have had to be sought for in scattered periodicals, not readily accessible to the general reader. No trustworthy book on the subject exists; generally, the experiences of others, especially those of the Austro-Hungarian Technical and Administrative Military Committee, having been simply copied, and not unfrequently misunderstood.

I therefore venture to think that the following pages, now at length laid before the Profession, will be found useful as a practical contribution to the subject. What I have aimed at is to offer to engineers actually engaged in conducting blasting operations such information as may be depended upon. I have attempted to give in a concise form all that has been *proved* good and correct in the various methods of procedure.

Some of the deductions, formulæ, and indications are not precisely those usually given; but I would rather that my work should be criticised on theoretical grounds, than lay myself open to reproach from those to whom it is my desire that the book should be a useful companion.

In preparing the work, which was originally written in German, for the press, I have received much help from Mr. R. B. POLLITT, Assoc. M.Inst.C.E., Assoc. Inst.E.E., for some years my assistant engineer in connection with important explosive and chemical works. I have also to thank Mr. S. SINGER, managing director of the Société Centrale de Dynamite Nobel in Paris, for much useful information.

OSCAR GUTTMANN.

12 MARK LANE,
LONDON, E.C., *March* 1892.

PREFACE TO THE SECOND EDITION.

In preparing the second edition of this handbook I have brought the whole material up to date, more especially with regard to rock-drills and explosives.

Although great advances have been made in the theoretical consideration of safety explosives, I preferred to give a summary for practical men only, who can look the matter up in books dealing specially with explosives.

A number of new illustrations, and a specially compiled table of the "permitted" safety explosives, have been added.

OSCAR GUTTMANN.

12 Mark Lane,
London, E.C., *May* 1906.

CONTENTS.

CHAPTER I.

CHAPTER II.

CHAPTER III.

CHAPTER IV.

CHAPTER V.

CHAPTER VI.

CHAPTER VII.

CHAPTER VIII.

CHAPTER IX.

PAGE

CHAPTER X.

CHAPTER XI.

CHAPTER XII.

BLASTING.

CHAPTER I.

HISTORICAL SKETCH.

Invention of Gunpowder.—The early history of blasting is, of necessity, to a great extent identical with that of gunpowder, as for some centuries there was no other explosive available for blasting operations, and the perfecting of the methods of blasting was, therefore, largely dependent upon the improvements which were made from time to time in the manufacture of gunpowder.

Careful investigations made by the author have firmly convinced him that gunpowder was not suddenly invented. Many ascribe the discovery to a monk, variously called Berthold Schwarz, Bertholdus Niger, or Anklitzen, but no record substantiating this exists. By others it is attributed to a certain Typsilos or Altiral, and, in a more or less vague manner, it is said to have been invented by the Chinese, the Hindoos, the Arabians, etc.[1] On the other hand, it is quite certain

[1] More information about this matter may be found in the Author's book, "The Manufacture of Explosives," London, 1895.

that Roger Bacon in 1248 knew of gunpowder. Thanks to the investigations of Lieut.-Colonel Hime, it is now clear that certain obscure chapters in Bacon's book, "De potestate artis et nullitate magiæ," really contain instructions for refining saltpetre, and for the preparation of gunpowder; but it is doubtful whether he knew of its propellent properties.

The real origin of gunpowder seems without doubt to have been the "Greek fire" of the ancients, to the composition of which different materials were added from time to time, leading, about 1310–1320, to the discovery of the propelling properties of the improved mixture, and eventually to "gunpowder," as we know it.

For some three centuries, the exclusive use of gunpowder was in firearms. As late as 1617 Löhneyss wrote:[1]

"Auff den schneidigen Gängen arbeitet man mit Keilhawen / Auff den festen aber mit Bergkeisen und Handfeustel / . . . . Auff dem festen Gestein im hangenden / arbeitet man mit stärkeren vnd grösseren Bergkeisen / dann man verfähret die Gänge gemeiniglich im hangenden / Auff dem gar festen Gestein setzt man mit Fewer."

This proves that blasting cannot have been invented, as has been asserted, by Martin Weigold (or Weigel) of Freiberg in the year 1613. It is seldom that an important process is suddenly invented, and the art of blasting is no exception. It seems to have been gradually developed, like most great inventions and

[1] "On the soft veins they work with pickaxes, but in the solid ones with gad and mallet. In the solid rock in the roof they work with stronger and larger gads, because they generally work the veins in the roof; in the too solid rock they kindle a fire."

methods, by successive improvements introduced by various workers.

In the "Bergwerckschatz" of Elias Montanus (Frankfort, 1622) is to be found, under the heading "de Pvlta" ("of the breaking-tool"), a description of a copper ball filled with "good" gunpowder, covered outside with cotton soaked in saltpetre, and dipped into a mixture of pitch and sulphur. The ball had in it a hole the size of a quill-pen, through which the flame was projected. This ball was ignited and thrown into the shaft or tunnel to drive out by its explosion the smoke that had accumulated from working "by fire." A caution is added, recommending that the mine be carefully examined before using this means, in order that no damage may occur, because the ball sometimes bursts unexpectedly. Another use of the ball was sending it on in front as a scout, when examining old workings, to ascertain if anything were liable to "break away."

It is very likely that these breaking effects suggested the putting of the gunpowder directly into natural fissures; in fact, old records mention that originally natural, and afterwards also artificial, fissures were thus used, wooden wedges being driven in, after charging, to increase the effect. The making of bore-holes was not thought of till some time later.

Blasting: First Recorded Attempts.—The author's researches into the early history of blasting operations have shown that the first to use gunpowder for the purpose of throwing down rock in mining work was Caspar Weindl, who must, therefore, be regarded as the inventor of blasting.

On February 8, 1627, he performed the first blasting work, of which there is any authentic account, in the Oberbiberstollen of Schemnitz in Hungary. Through the kindness of Anthony de Péch, Esq., Ministerial Counsellor, the author has had the opportunity of inspecting the record of this in the Proceedings of the Schemnitz Mine-tribunal for the year 1627 (page 37). It is as follows:[1]

"Adi 8. Februari, dits 1627 Jars, hat die Gancz Löblich Gewerkschafft beim hauptperkhwerch Ober Piberstolln, Ihr kai: Mai: perggericht zur Schembnitz zur Einfart wegen des Casper Weindlsz Sprengwerch solches in Augenschein zunemen, ob es dem Gezimerwerch durch dasz schiessen schedlich sein mechte, in beratschlagung zu ziehen begrueszt, Über solchem eingenomenen Augenschein, vnd in

[1] "Feb. 8th, A.D. 1627. The very honourable Company of the main mine at Ober Piberstollen, having begged his Imperial Majesty's Mine-tribunal of Schemnitz to inspect the blasting-work of Caspar Weindl, and to consider whether it would be likely to damage the mine, a shot was fired in the presence of the mine-officials and the Mine-tribunal. After inspection, it was found that the blasting might be executed, and would not cause any harm; that though smoke is developed, it passes away in a quarter of an hour, taking with it much foul air, and does no harm to the miners; but that it would not do to 'shoot' too frequently, because of obstructing the other gangs engaged in picking and loading ore, as they would have to stop work frequently. That in the Daniel Mine, where there are nice loads (though very hard), but no miners available to work them, blasting could be used with advantage both in the shafts and in the headings.

"After the blast, Caspar Sprenger ('blaster,' the nickname now given to Weindl) was asked if he would contract for the working in the Daniel heading, as the single place on the lowest level would not bear the expense. This he agreed to do, if supplied with 40 or 50 good miners. As work had been stopped in the lowest level for want of labour, he was asked if it would be possible to obtain the men he wanted from some other district. Caspar undertook to bring a number of good hewers from Tyrol, provided expense be neither considered nor spared, and a passport of his Imperial Majesty be obtained.

"Thus doth the Imperial Mine-tribunal report to the very honourable Company, which, without prejudice to such council, will allow to be put into operation the promise and offer of Caspar Sprenger.

"Given Schemnitz, Feb. 16th, 1627. Geörg Putscher, mine master; Caspar Pistorius; Chri: Spilberger, clerks to the Mine-tribunal."

Gegenwart der Ambtleut, Sowol des Perggerichts, beschehenen Schusz hat sichs befunden, dasz dieses Sprengwerch wol fürzunemen sei, vnd nichts schedlichs causirn werde, ob zu Zeitten gleich ein Rauch entstehet, vergeet•er doch in ainer Viertl Stundt, vnd ist den hewern ohne schaden, nimbt auch viel böses Wetter mit sich wegkh, Aber offt zu schiessen, würde es nit thuen, denn es würde die andern khüren im Arzthauen—vnd Geföl, wenn Sie offt sollen stilhalten, verhintern, Aber für Rahtsamb wär, die weillen im Danielschlag schöne Anbrüch vorhanden, die aber Zimblich fesst, doch keine heüer die man zuelegen mechte vor handen sein, daselbst: So wol in den Schächten—vnnd Stolwenten auf der Soolen, liesz sich dasz Sprengwerch gar wol an.

"Weiter ist damallan Caspar Sprenger befragt worden, ob er diese Örtter im Danielschlag wollte zu Lehenschafft annemben, Weil das ainczige Ortt im tieffisten, den Vncosten mit dem Sprengen nicht ertragen würde, hierüber meldt solcher, wenn man Ime 40 oder 50 guette Heuer gibt, So traue er Ihme dise Örter gar wol mit der Herrn Gewerckhen guetten Nuczen zu Lehenschafft anzunemben.

"Auf solch sein erpieten wird Ime Caspar darauf geantwort.

"Weil im Tieffisten viel Örtter aus Mangel Heier feiern müssen, vnnd dits Orts allein ein 40 Heier von Nöten, vnd sein doch keine vorhanden, ob man nit Mitl haben könne, Sovil Heier etwo von andern Ortten herzubringen.

"Darauf meldt Caspar, wann man den Uncossten, der darauf geen würde, nit ansehen, noch Sparen wolt, vnnd Ime ainen Paszbrieff von Ihr Kai: Mai: ausbringen vnd ertailen würde, trauet er Ime gar wol ausz Tyroll ain anzoll guetter Heier, zu Notturfft an solche Örtter als in das Tieffeste, Danielschlag, hinternkünsten, Schächten, Stolwant, an der Sol: vnnd andere Örtter zuezuweitten, vnd ins werkh zusetzen, herein zu bringen."

"Souil thuet das kaiserlich Perggericht ain Gancze Löbliche Gewerckhschaft berichten, welche ohne maszgeben auf solcher verern beratschlagungen des Caspar Sprengers Zuesagen: Vnnd erpietten ins Werckh zuseczen wissen werden, Datum Schembnicz den 16 Februari A. 1627. Geörg Putscher Pergkmaister, Caspar Pistorius, Chri: Spilberger Perggerichtsschreiber."

Caspar Weindl, before coming to Schemnitz, had evidently worked in the Tyrolese mines of Count Montecuccoli, then Oberst Kammergraf (chief of the mining district) of Schemnitz; but it is not clear whether Weindl had practised blasting there, and was on that account called to Schemnitz, or whether the operation of Feb. 8, 1627, was his first experiment in actual blasting for mine-work. From Schemnitz the practice of blasting spread to Bohemia and the Hartz.

Rössler's "Hell polirter Bergbauspiegel" ("Brightly Polished Mining-Mirror"), 1700, says: "Shooting came into Germany from Hungary, first into Grösslass (Graslitz of to-day), and then into the Hartz Mountains, whence it has spread all over." This spreading did not, however, take place very rapidly.

Von Born mentions that he found at Dilln, near Schemnitz, large bore-holes, with the date "1637" cut over them. According to Calvör, blasting was introduced into the mines at Clausthal in 1632, and Hoppe gives 1645 as the year in which it was first used at Freiberg; in 1724 it was introduced into Sweden, but into the salt-mines at Aussee not until 1768.

As regards the introduction of gunpowder into English mines, the author has found but few records. A writer of the past century says that it was brought into England in 1670 by German miners; but the author has failed to trace the original source of this statement. It certainly was not known in the lead-mines of Derbyshire before the 10th of October 1665, because one of the articles made at "The Great Barmote Court," which was held on that date at Wirksworth, runs as follows: "Art. XL. We say that any miner in an open rake may kindle and light his fire after four of the clock in the afternoon, giving his neighbour lawful warning thereof."[1]

As to Cornwall, gunpowder seems to have been introduced into the Godolphin mine near Breage in 1689. The register of burials of Breage contains the following quaint entry: "Thomas Epsly Senior of Chilchumpton pish of Bath and wills in Sumersitsheere he was the man That brought that rare inuention of shooting the rocks which came here in June 1689 and he died at the ball and was buried at breag the 16 day of December in the yeare of our lord Christ 1689."

Writing as late as 1670, Edward Brown, an English physician, who visited and described most German and Austrian mines, could report with surprise from Herrengrund near Neusohl (Hungary), as follows: "And one place they shewed me, where there had been a pernicious Damp, and yet the Rock so hard, that it could not be broken by their Instruments; but the descent was all made by the means of Gun-pouder rammed into long round holes in the Rock, and so blown up."[2]

Progress in Methods Employed.—When bore-holes first came into use they were made with iron-mouthed borers, fairly large, nearly 3 inches in diameter, and then closed with a wooden plug, termed the "shooting-plug."[3]

[1] "Lead and Lead Mining in Derbyshire," by Arthur H. Stokes, F.G.S., H.M. Inspector of Mines. London, 1880. "The Complete Miner," by Thomas Houghton. London, 1681.

[2] "A Brief Account of some Travels in Hungaria," by Edward Brown, M.D. London: Benj. Tooke. 1673.

[3] Paper read by Professor Franz Rziha on January 5, 1878, before the Austrian Society of Civil Engineers and Architects. (See, also, his work on "Tunnelling.")

Henning Hutman, in 1683, employed a kind of drilling-machine. In 1685, clay tampings, and in 1686, firing-tubes began to be used. In 1689, paper cartridge cases were used to replace the older form of leather, and in 1717 bore-holes of smaller diameter came into vogue.

The use of the chisel-borer dates from 1749, blasting the untouched breast from 1767 (first at Zinnwald). Alexander v. Humboldt was the first, in 1790, to use hollow charging; and Snow-Harris, in 1823, applied electricity to the firing of charges.[1] The safety fuse was invented by Bickford in 1831, and drilling by aid of compressed air was introduced by Brunton and Bartlett in 1854.

Until 1854 (that is, for 227 years after the first application), gunpowder was the sole agent available for blasting, but the succeeding fifty years have seen it to a great extent driven from the field by more modern explosives.

High Explosives. — The discovery of **gun-cotton**, following the experiments of Braconnot (1833), Pelouze and Dumas, was made nearly simultaneously by Schönbein of Bâle and Böttger of Frankfort in 1846.

In 1853, Lieutenant-Field-Marshal Baron v. Lenck erected a gun-cotton factory in Austria; operations there had, however, to be discontinued on account of repeated explosions, due to the imperfect methods of manufacture employed. Sir Frederick Abel, chemist

[1] As a matter of fact, as early as 1804, at Konowitz in Austria, in the presence of the Emperor and Empress, Major Baron Chastel fired a series of military mines by means of "frictional electricity," laying his wires across the intervening river. (Blasek, "History of the I. R. Engineering Corps.")

to the British War Office, continued nevertheless to investigate the subject, and, by adopting a method of purification, which was invented by John Tonkin, junr., of Poole, in 1862, he so improved the process of manufacture that gun-cotton has since been manufactured with success and safety.

In 1846, Ascanio Sobrero, Professor of Chemistry at Turin, discovered **nitro-glycerine.** For a long time, however, its only use was in medicine, in the form of a very dilute alcoholic solution, known under the name of Glonoine, as a remedy for angina pectoris. A Swedish engineer, Alfred Nobel, commenced experimenting with it as an explosive as early as 1863. After many trials he discovered that it could be exploded by small primers of gunpowder. Used alone, being liquid, it was difficult to handle, and many inconveniences and dangers attended its employment for blasting purposes. After experimenting with many absorbents, Nobel found, in 1866, one suitable for his purpose, namely, kieselguhr, and in 1867 he introduced a mixture of nitro-glycerine and this material under the name of **dynamite.**

In 1867, he also patented the use of fulminate of mercury detonators for initiating the explosion, and since that time dynamite rapidly assumed the important place which it has since maintained in blasting operations.

From 1867 to 1875, many attempts were made to evade Nobel's patents by substituting other absorbents for kieselguhr, but without any material success.

The next move forward was also due to Nobel. He discovered that certain forms of gun-cotton were capable of converting, under suitable conditions, as much as fifty times their weight of nitro-glycerine into a tough jelly-like mass. This material he named **blasting gelatine**, and it is one of the most powerful explosives known. The various gelatine dynamites were evolved from it by Nobel by incorporating with it different mixtures. These are now the most approved and extensively used blasting agents.

The large number of explosions in fiery mines induced various governments, in 1885, to investigate the use of explosives, and although at first many erroneous conclusions were arrived at, it was found possible later on to devise explosives that are reasonably safe. The starting-point for them was an invention made by Dr. Herman Sprengel, F.R.S., in 1871; the first to prove safe in the hands of Mr. Margraf of Neunkirchen were Hellhoffit, an otherwise useless mixture of nitric acid and tar, and Carbonite, which in point of safety has not yet been surpassed by any of the numberless safety explosives that have since been put on the market.

Blasting Works.—The first blasting work undertaken on a large scale was the Malpas Tunnel for the canal at Languedoc in the year 1679. In 1696 followed the first road on the Bergüner Stein in the Abula Pass. The road over the Semmering was commenced in 1728, that over the Brenner in 1772, that over the Arlberg in 1797, and the one over the Simplon in 1801. The great adits at Schemnitz and Bleiberg, which, during a century, had advanced very slowly by aid of gun-powder, progressed more rapidly in ten years by the aid of machine-drilling and dynamite than in the whole of the previous period.

The Mont Cenis, St. Gotthard, Arlberg, and Simplon tunnels, the numberless railroads connecting widely separated towns, the extraordinary development of iron and coal mines, and, following these, of machines, construction-works, and generally of most industries, may be said to have been made possible by the rapid progress of blasting, which has, without doubt, been a most important factor in the advance of civilisation during the last century.

CHAPTER II.

BLASTING MATERIALS.

EXPLOSIVES are, according to Trauzl's definition, such bodies as, in an extremely short time, and in a small space, develop very large quantities of heat and gases, exerting enormous pressures upon the surrounding bodies, and are able, by the expansion of the highly heated gases, to perform a considerable amount of work.

A great number of combinations are known which are capable of exploding—for instance, fire-damp, flour-dust, coal-dust, etc., as well as oxyhydrogen gas, nearly all the chloric salts, chloride and iodide of nitrogen, and numberless nitrogen and other compounds. For practical purposes, however, only a small number can be utilised, and only a fraction of these as blasting materials.

Blasting materials proper are explosives having a destructive action, as distinguished from the "propelling" action of explosives used for artillery and firearms. Most of these latter explosives could indeed be employed in blasting; but the expense of manufacture, and their relatively small efficiency for this purpose, render them unable to compete with the explosives specially adapted for blasting.

The proper characteristics of explosives for this latter purpose are: (1) sufficient "stability"; (2) difficulty of detonating by mechanical shock; (3) handy form; (4) absence of injurious effects on the health of those using them; and, of course, (5) sufficient strength of action. Much disappointment, as well as loss of time and money, might be avoided if manufacturers and users would only examine, from these points of view, the many new explosives that are brought out from time to time.

Following a suggestion made by General Hess, explosives are generally divided into two classes or groups, viz.:—

I. Low explosives: direct exploding materials.

II. High explosives: indirect exploding materials.

Class I. includes all those that can be made to develop their force by direct means, such as ignition.

Class II. is made up of those which require an intermediate agent, such as a fulminate detonator, to cause them to explode properly.

Mr. Bichel has proposed a division into three classes: (*a*) those that can be ignited by fire alone; (*b*) those requiring a cap for initiating detonation; and (*c*) those that can be made to explode direct by fire (as fulminate of mercury). For practical purposes, however, Hess' classification is preferable, since, with very few exceptions, all explosives used in practice can be included in either class (*a*) or (*b*).

I. DIRECT EXPLODING MATERIALS (LOW EXPLOSIVES).

a. **Blasting Powder.**—From the time of its discovery, until quite recently, gunpowder has always had the same components—viz., saltpetre, sulphur, and charcoal.

Some twenty years ago the Rottweil-Hamburg Gunpowder Factory (in England, the Chilworth Gunpowder Co.) introduced the so-called "brown" or "cocoa" powder for use in large guns, which contains carbonised rye-straw, in place of the ordinary charcoal used; but its use has now been practically discontinued. W. Güttler also proposed a special charcoal for gunpowder making. Not only have the components remained practically unaltered, but their relative amounts also have hardly varied since gunpowder has been known. A good gunpowder contains 75 parts of saltpetre, 10 parts of sulphur, and 15 parts of charcoal, but slightly different proportions obtain in different countries. In Germany, for instance, the mixture is saltpetre 70 parts, sulphur 14 parts, and charcoal 16 parts. Up to a certain point, the "quickness" (rapidity of explosion, in Germany called "Brisanz") of gunpowder increases with the amount of saltpetre—that is, with the amount of *oxygen*. Blasting-powder should have great "quickness," and also give off large quantities of gases, to obtain which its composition is modified.

In England and Germany, gunpowder and blasting-powder have the same composition, the slower combustion of the latter being obtained by shorter treatment and larger grains.

The following Table shows the composition of blasting-powder in different countries :—

Ingredients.	Great Britain.	Germany.	Austria-Hungary.	France.	Russia.	Italy.
Saltpetre .	75	70	60.19	72	66.6	70
Sulphur .	10	14	18.45	13	16.7	18
Charcoal .	15	16	21.36	15	16.7	12

The composition of nearly all blasting-powders, wherever made, falls within these limits.

In consequence of the strong competition from dynamite, manufacturers have been forced to make their blasting-powders as "quick" as possible, and blasting-powder is sometimes made containing 76 parts of saltpetre, 9 parts of sulphur, and 15 parts of charcoal. This may be regarded as the practical limit for the increase of force of blasting-powder; for, beyond it, single properties can only be increased at the expense of others equally important.

Manufacture of Gunpowder.—In the manufacture of gunpowder, the purity of the ingredients is of the highest importance. Only highly refined saltpetre is used—it must not contain even $\frac{1}{200}$ per cent. of chlorine; pure sulphur, entirely free from sulphurous acid and arsenic; and charcoal made from specially selected wood, prepared most carefully at fixed temperatures. The woods most generally used are dogwood, willow, and alder. Occasionally, lime-tree and hemp branches are substituted. For blasting-powder, the so-called "black charcoal" is used, which is made by charring wood at about 660° F. in special cylinders.

The various ingredients are carefully pulverised, and mixed with the addition of water. Each substance is either pulverised separately, and the mixture made afterwards; or the sulphur and charcoal, or the saltpetre and sulphur, are pulverised together. Sometimes all three are pulverised together, when the mixing or incorporation goes on simultaneously with the pulverising.

Formerly, this work was mainly done by stamp-mills, the stamps and troughs being of metal or wood, the time of stamping varying from twenty-four to sixty hours. In Switzerland, the tilt-hammer, which is similar in its effect, was used instead of stamps.

FIG. 1.

FIG. 2.

"Incorporating" mills, however, are now mostly used, and they reduce the time of pulverising to between six and ten hours. For small-arm powders the binary mixture (sulphur and charcoal) is still in some factories treated in revolving iron barrels or drums, and the tertiary mixture in similar barrels of wood, lined with leather. Inside these drums are balls of bronze or hard wood, which perform the operations of incorporating and mixing as the drums revolve.

The next step is the compressing of the mixture into dense cakes by means of screw, roller, or hydraulic presses. The pressed cakes are then broken up with wooden mallets, and the pieces passed on to the graining-machine. Lefèbvre's graining-machine has a wooden disc, weighted with lead, grooved on its face like a millstone; this granulates the powder, which is then classified by a series of sieves revolving about an eccentric axis. In Congrève's graining-machine, a series of rollers, placed one above the other, takes the place of the disc in the above-mentioned machine. These rollers have teeth and grooves cut in them, the sieves for classifying being arranged underneath. After graining, the gunpowder is partially dried and then dusted, usually in revolving sieves. The next operation is glazing, that is, polishing the surface of the grains. This is effected in revolving barrels, made of wood, by the friction of the grains against each other.

After glazing, all moisture is driven off in suitable drying-houses, and the grains are again dusted. This last drying must be effected completely, but slowly; for if it is hurried, the sudden development of steam loosens the consistency of the grains, and they become more sensitive to the absorption of moisture from the air when stored, to say nothing of other inconveniences.

Of late years, the practice of using compressed blasting-powder has become more and more general.

The powder, still containing from 2 to 3 per cent. of moisture, is moulded, chiefly by hydraulic presses, into solid cylinders (Fig. 1), which generally have a slightly conical axial hole to receive the fuse. In Great Britain this hole is sometimes made more conical (Fig. 2), so that the bent end of a fuse will stick fast in it, and the cartridges can be slipped on to the fuse, and inserted all together into the bore-hole.

b. **Various Powder Mixtures.**—Various powder mixtures, having partly different ingredients, are made chiefly in Austria-Hungary, where the gunpowder monopoly causes high prices, and enables such mixtures to compete with gunpowder.

They differ as a rule from ordinary gunpowder in the substitution of some other form of carbon, or sometimes cellulose for the charcoal, and of some other nitrate, usually nitrate of soda, for the saltpetre. Almost all contain a small percentage of some material which forms the pretext for evading the monopoly, but which generally lessens the efficiency of the mixture, and is frequently so out of place as to create amusement amongst experts. They are often manufactured without special care, and their use is only due to strong local causes.

The following are the compositions of some such powder-mixtures still in use:—

Diorrexine:

Saltpetre	42.78	parts.
Nitrate of soda	23.16	„
Sulphur	13.40	„
Charcoal	7.49	„
Beech sawdust	10.97	„
Picric acid	1.65	„
Water	0.55	„

Haloxyline:

Saltpetre (or sodium nitrate)	75	parts.
Sawdust	15	„
Charcoal	$8\frac{1}{3}$	„
Potassium ferrocyanide	$1\frac{2}{3}$	„

Petralite consists of saltpetre, sulphur, wood-pulp, and powdered coke.

Janite:

Saltpetre	70	parts.
Sulphur	12	„
Lignite coal	18	„
Picric acid	0.4	„
Potassium chlorate	0.4	„
Calcined soda	0.3	„

Carbo-azotine (formerly made in England under the name of "Safety blasting-powder"):

Saltpetre	64	parts.
Sulphur	12	„
Soot	7	„
Tan or sawdust	17	„
Sulphate of iron	1–5	„

Azotine consists of sodium nitrate, sulphur, charcoal, and petroleum residue.

Amidogène:

Saltpetre	73	parts.
Charcoal	8	„
Bran (or starch)	8	„
Sulphur	10	„
Magnesium sulphate	1	„

To cheapen the production, as in the case of "Safety blasting-powder," "Amidogène," etc., other processes of manufacture have been proposed, such as dissolving the soluble ingredients in water, mixing in the others, and evaporating to dryness.

This process was practised long ago by the Tartars, but it is impossible to obtain a thorough incorporation, and, therefore, a good powder, by these means.

Under the head of powder-mixtures must be classed those in which the saltpetre is replaced by potassium chlorate. Chlorate mixtures were frequently devised, the incentive to this being the higher efficiency of potassium chlorate compared with potassium nitrate; their use could not become general on account of their great sensitiveness to blow and friction. Of late years this has been overcome by the addition of a small quantity of oil, paraffin wax, or similar greasy matter. This addition, if effective, prevents the explosion by mere ignition, and consequently such explosives belong to the class of "indirect exploding material."

The following are the compositions of a few of the powder-mixtures having potassium chlorate in place of potassium nitrate, which have been used to some extent. Very many have been invented, and always with protestations that they would revolutionise all operations in which explosives are used:—

Himly Powder:

Potassium chlorate	45 parts.
Saltpetre	35 „
Coal-pitch	20 „

the latter dissolved in benzine, which is evaporated after mixing.

Poudre des Mineurs (Miners' Powder):

Potassium chlorate	50 parts.
Manganese	5 „
Bran	45 „

Comet Powder:

Potassium chlorate	75 parts.
Resin	25 „

II. INDIRECT EXPLODING MATERIALS (HIGH EXPLOSIVES).

Properly speaking, all the direct exploding materials can also be detonated by indirect means, and in most cases their effect will be materially increased by doing so. But in Class II. are placed only those explosives which cannot be made to develop their force except by an initiating detonation.

Most indirect exploding materials at present known are compounds produced by the action of nitric acid upon carbon compounds; this action is termed "nitration," and the results of it are called "nitro-compounds."

The nitro-compounds, which can be properly called explosives, are only produced when the acid used is of the highest concentration. Weaker acid produces inferior nitric ethers, of which collodion cotton (di-nitro-cellulose) is the one much used as an ingredient in the manufacture of explosives.

a. **Gun-cotton.**—Cotton waste is first freed from grease and other impurities by "teasing" and treating it with a solution of soda. It is then immersed in a bath of acid, consisting of a mixture of one part of nitric and three of sulphuric acid. The bath should contain from thirty to fifty parts of acid by weight to one of the cotton immersed. The object of the sulphuric acid in all nitrating processes is to absorb the water formed during the operation, and thus maintain the concentration of the nitric acid.

When the nitration is completed, the cotton is freed from acid in a centrifugal dryer. Repeated washings with hot and cold water, with the addition of soda, alternating with drying in hydro-extractors, follow. It is then reduced to pulp by a beating machine, again washed, and dried in a centrifugal machine. Finally, when quite free from acid, it is made up into various forms, depending on the purpose for which it is to be used. It is either left in the loose state, or moulded whilst moist into cartridges of suitable form by an hydraulic press. For blasting operations, the cartridges have a central hole similar to those of gunpowder. Frequently, these blasting cartridges contain a certain amount of some nitrate. *Tonite* made by the Cotton Powder Co., and the mine cartridges from Düren, contain 52.5 parts of gun-cotton to 47.5 of barium nitrate. *Potentite*, formerly made by the Potentite Co., consists of gun-cotton and saltpetre.

Collodion Cotton is manufactured in a similar manner to gun-cotton, except that nitric acid of lower concentration is used. It is employed in making blasting gelatine and the various gelatine dynamites.

b. **Nitro-glycerine and Dynamite.**—Nitro-glycerine is formed by the action of nitric acid upon glycerine, and its manufacture on a commerical scale is now an extensive industry.

The nitric acid and glycerine used must both be of the greatest purity. This is of the highest importance, as on it depends the stability of the nitro-glycerine when stored, and the absence of deleterious fumes when exploded, as well as freedom from danger whilst it is being made.

The mixture of sulphuric and nitric acid is contained in a large vessel of lead, fitted with cooling and agitating arrangements. The glycerine is allowed to run in very gradually, the temperature being most carefully observed by thermometers, and regulated by the cooling arrangements. Sight glasses, and other similar instruments, allow for careful watching of the process, and for regulating it. The nitro-glycerine, when ready, is separated from the mixed acids in a second apparatus, and then goes through a series of washings and filtrations until it is perfectly neutral. The refuse acids are treated in a second separating apparatus to remove the last traces of nitro-glycerine, and are subsequently decomposed in a de-nitrating apparatus to recover the nitric and sulphuric acids. In some American backwood factories nitro-glycerine is still made in a series of earthenware pots with mechanical agitators, the whole contents of which—acid and nitro-glycerine—are then thrown into water, where the nitro-glycerine is allowed to settle, the acids being of course wasted.

Before the invention of dynamite, liquid nitro-glycerine was used in mines, being transported and stored in tin bottles; but the danger and inconvenience of this method soon caused it to be discontinued. Mowbray, of North Adams, Mass., U.S.A., introduced, and for a long time used, the method of freezing the nitro-glycerine. The greater convenience and trustworthiness of dynamite, however, soon caused the use of liquid or frozen nitro-glycerine to be discontinued, and at present it is only employed in America for increasing the flow of oil-wells by "torpedoeing."

By mixing nitro-glycerine with suitable absorbents, a material is formed, to which, as before mentioned (p. 9), Nobel gave the name of **dynamite**.

The absorbent chiefly used is "Kieselguhr," a very bulky silicious earth, which consists entirely of the microscopic shells of Diatomeæ. It is found in the Lüneburg moors in Hanover, in the Siegen district, in Scotland, in Italy, and in other places. One factory has used "Limeguhr," a calcareous tufa found in stalactite caverns and old watercourses; it is with this absorbent that *white dynamite* was made. The manufacture of kieselguhr dynamite has been practically given up in every country except Great Britain, where a certain amount is still produced, chiefly for exportation.

Various absorbent materials of an organic nature have been tried from time to time, such as cellulose, decayed wood, etc., which were mixed with different nitrates, since it was believed that the absorbent should also be explosive (or, at least, combustible) if the full weight of the charge was to be utilised. But as these substitutes for kieselguhr have usually a lower absorbing power, any advantage occurring from their burning or exploding is counterbalanced by the smaller amount of nitro-glycerine absorbed, while the total force is not greater, or is even less, than where kieselguhr is used. Nevertheless, such dynamites with partly organic "dope" are largely used in America, because by this means lower grade explosives for softer rock, quarries, etc. can be produced.

The composition of the most generally used dynamites is as follows:—[1]

Dynamite (in Germany, Italy, etc. called Dynamite No. 1 or Kieselguhr dynamite; in America, Giant-powder):

Nitro-glycerine	75	parts.
Kieselguhr	25	„
Sodium carbonate	0.5	„

"40 per cent." dynamite (the one chiefly used in America):

Nitro-glycerine	40	parts.
Sodium nitrate	47.25	„
Wood-pulp	11.75	„
Calcium carbonate	1	„

Carbonite:

Nitro-glycerine	25	parts.
Wood-meal	40	„
Potassium nitrate	30.5	„
Barium nitrate	4	„
Sodium carbonate	0.5	„

Hercules Powder (America):

Nitro-glycerine	40	parts.
Sodium nitrate	45	„
Wood-pulp	11	„
Sodium chloride	1	„
Magnesium carbonate	1	„
Moisture	2	„

Vulcan Powder (America):

Nitro-glycerine	30	parts.
Sodium nitrate	52½	„
Sulphur	7	„
Charcoal	10½	„

[1] For complete information see Captain Thomson's "Dictionary of Explosives," and the Author's book, "The Manufacture of Explosives."

Safety Nitro Powder (America):

Nitro-glycerine	68.81 parts.
Sodium nitrate	18.35 "
Wood-meal	12.84 "

Judson Powder (America):

Nitro-glycerine	5 parts.
Sodium nitrate	64 "
Sulphur	16 "
Cannel coal	15 "

Atlas Powder (America):

Nitro-glycerine	75 parts.
Sodium nitrate	2 "
Wood-meal	21 "
Magnesium carbonate	2 "

Vigorite (America):

Nitro-glycerine	30 parts.
Potassium chlorate	49 "
Saltpetre	7 "
Wood-meal	9 "
Magnesium carbonate, moisture, etc.	5 "

Rhexite:

Nitro-glycerine	64 parts.
Decayed wood	11 "
Wood-meal	7 "
Sodium nitrate	18 "

It is very important that, first of all, the components of the absorbent should be absolutely freed from moisture and from chemical or mechanical impurities. They have then to be very finely pulverised and thoroughly incorporated. This is especially true for the so-called "active" absorbents (or bases), for their efficiency is thereby increased, as in the case of gunpowder.

To prepare kieselguhr for making dynamite it is calcined, ground between rolls, and then sifted. Wood-meal, decayed wood, etc. are roasted, and sometimes boiled previously in a soda solution; saltpetre is thoroughly dried and then ground very fine. The compounds of active absorbents are incorporated in wooden drums, similar to those used in gunpowder-making, and have to be stored in closed receptacles. The mixing of the absorbents with the nitro-glycerine is usually effected by hand-kneading in troughs, the mixing being finished by repeatedly passing it through hair or metal sieves, to ensure thorough incorporation. This operation in some cases causes a diminution in volume of the absorbent, and a corresponding lowering of its absorbing power. This may be the cause of exudation, and the dynamite will become greasy to the touch, or drops of nitro-glycerine may even separate out.

After mixing, the dynamite is filled by piston-presses into cases of parchment or paraffined paper, forming the well-known dynamite cartridges of commerce. Cartridges of 3½ ins. and primers of 1 inch in length are most usually made, in the proportion of 4 to 1. They are packed in cardboard boxes containing 5 lbs. These are either wrapped in waterproofed paper and tied with string, or closed with glued strips and dipped in melted paraffin. Ten of these boxes—50 lbs. of dynamite (25 kilos. on the Continent)—are then packed in wooden cases.

The question of an absorbent has been admirably solved in **blasting gelatine** and the gelatine dynamites.

Collodion cotton—a lower form of nitro-cotton than gun-cotton—is soluble in ethers, of which nitro-glycerine is one. One-half per cent. of collodion cotton dissolved in nitro-glycerine completely transforms it into a jelly-like mass; and 8 per cent. of collodion cotton, as taken to blasting gelatine, makes a firm, tough, horn-like material. Thus, whilst 80 per cent. is the maximum amount of nitro-glycerine that can be safely present in kieselguhr dynamite, gelatine may contain even 97 per cent.

The various nitro-cottons differ by the amount of combined nitrogen. Hexa-nitro-cellulose,[1] or gun-cotton, is insoluble in ether-alcohol; the others are soluble. The manufacture of collodion cotton is now so perfected that, as made at present, it consists almost exclusively of soluble nitro-cellulose, enabling the best results to be obtained.

In making blasting gelatine, the nitro-glycerine is first warmed in a special apparatus and the proper proportion of thoroughly dried collodion cotton added. When this is completely dissolved, the solution is thoroughly mixed until the gelatine assumes the right consistency. If gelatine dynamite is required, the dope is added at this stage, and the mixture thoroughly incorporated in special mixers. The blasting gelatine, or the gelatine dynamite, as the case may be, is then formed into cylindrical cartridges by suitable presses, and packed like dynamite.

[1] Generally, only six stages of nitration are recognised—viz., mono-, di-, tri-, tetra-, penta-, and hexa-nitro-cellulose; the latter is then gun-cotton. Modern investigations, however, have confirmed the author's view that there is no strict line of demarcation between low and high nitrated celluloses.

In order to make blasting gelatine insensible to violent shocks, such as the blow from a projectile, when being used for military purposes, camphor is added; but by this means the sensibility to shock is so much decreased as to necessitate the use of special primers to explode it.

Blasting Gelatine (Gomme explosive) usually consists of 92 parts of nitro-glycerine to 8 of collodion cotton; occasionally some saltpetre is substituted for part of the latter.

Gelatine Dynamite consists of 80 parts of blasting gelatine to 20 of the same absorbing powder as is used for Gelignite (see below).

Gelignite (called in Germany Gelatine Dynamite No. 1) consists of:

65 parts of gelatine, containing	$96\frac{2}{13}$ parts	Nitro-glycerine	or 62.500	per cent.
	$3\frac{11}{13}$,,	Collodion cotton	,, 2.500	,,
35 parts of absorbing powder, containing	75.0 ,,	Saltpetre	,, 26.250	,,
	24.0 ,,	Wood-pulp	,, 8.400	,,
	1.0 ,,	Soda	,, 0.350	,,
			100.000	,,

Most foreign dynamite factories also make dynamites of inferior strength, the use of these being in many cases advantageous. For example, *Gelatine Dynamite* No. 2 contains 45 parts of gelatine to 55 of absorbing powder; *Dynamite* No. 3, 14 parts of nitro-glycerine to 86 of an absorbing powder, containing:

70 parts	Sodium nitrate	or 60.20	per cent.
15 ,,	Sulphur	,, 12.90	,,
14 ,,	Charcoal	,, 12.04	,,
1 part	Soda	,, 0.86	,,
		86.00	,,

Specially strong gelatine dynamites are also made by the addition of ammonium nitrate. *Ammonia gelatine, extra dynamite*, etc. belong to this class.

Within the last year the Castrop Safety Explosives Company have taken up a patent of Dr. Anton Mikolajczak for making **dinitro-glycerine.** This is a nitro-compound of glycerine containing a smaller percentage of nitrogen, and having the remarkable property that it does not freeze, and, if mixed with trinitro-glycerine, prevents this from freezing. It is, on the other hand, somewhat hygroscopic and of inferior strength, besides being more expensive to make. As yet, no explosives containing dinitro-glycerine have been brought on the market; but the Castrop factory proposes to make such explosives containing about 35 per cent., the remainder being ammonium nitrate, with perhaps some absorbent carbon compound like wood-pulp.

c. **Other Nitro-compounds.**—None of the many carbon compounds that have been subjected to nitration have as yet given products which can equal nitro-glycerine in all its qualities, since glycerine can be made almost chemically pure, and thus no unusual component is present to hinder nitration. The influence of impurities upon the yield and quality of the nitro-compound is larger than is generally assumed. Further, glycerine is a liquid which readily mixes with the acids without any violent reaction, so that every small particle comes instantly in contact with the acids and is nitrated.

There are, of course, other liquid carbon-compounds which can be nitrated, and which can be produced of sufficient purity; but, either their higher nitro-compounds can only be produced at great expense and with difficulty, or, when produced, their explosive force is either too violent or too weak. Thus, for instance, commercial nitro-benzine is only a mono-nitrate, and is almost non-explosive by itself. The manufacture of di- and trinitro-benzine, on the other hand, is complicated and expensive, whilst explosives made from them are apt to give off injurious gases on explosion.

Straw nitro-cellulose always contains many impurities, derived from those originally in the straw. Nitrated wood is easier to make, but its explosive power falls below that of gun-cotton.

It may be generally stated that all the nitro-compounds similar to those just mentioned are inferior to nitro-glycerine, because they contain less nitrogen and more non-nitrated compounds. This is partly because the acid cannot be made to penetrate them completely, and partly inherent to their chemical composition. The following bodies, amongst many others, have been nitrated, and the resulting nitro-compounds tried as explosives:—Wood (Schultze powder), Straw (paleïne), Paper (pyro-paper), Bran (Lannoy's powder), Starch (nitro-starch), Sugar (nitro-sugar), Mannite (nitro-mannite), Milk-sugar (nitro-lactose), Molasses (nitro-molasses), Curd (Sjöberg's explosive), Phenol (picric acid), Cresol (nitro-cresol, for military purposes), Benzol (nitro-benzine), Toluene (trinitro-toluene), Naphthaline (nitro-naphthaline), Coal (by Hellhoff).

Nitro-celluloses do not contain sufficient oxygen for complete combustion, and therefore produce a large amount of carbon monoxide; nitro-benzine and picric acid both give off a large quantity of deleterious fumes, if incompletely exploded.

Many of these compounds have been utilised in the manufacture of safety explosives, about which more will be said later on.

d. **Sprengel's Liquid Acid Explosives.**—As mentioned above, Sprengel described, in 1873, a number of blasting mixtures, which developed great force, but which were quite unmanageable; he himself declared them to be quite impracticable. In spite of the opinion of the inventor of this kind of explosive, however, others have reverted again and again to the idea of an explosive, the last stage of whose manufacture is the mixing of the ingredients at the place where it is to be used. Nevertheless, they are sources of danger, and it is imprudent to increase the number of possible causes of accident in mines by having these mixings made there, instead of in an explosives factory, where, in addition to the manipulation being done by experienced hands, proper precautions are taken to prevent and to limit the effects of accidents.

e. **Safety Explosives.**—In consequence of researches made by government committees of all interested countries, various explosives have been proposed and successfully introduced which are comparatively safe in the presence of fire-damp. The following tables contain the "permitted" explosives which are licensed in this country for use in accordance with the Coal Mines

[*To face p.* 33.

roduction Prohibited.

Potassium chloride	Sodium chloride	Magnesium sulphate	Sodium sulphate	Potassium bichromate	Ammonium oxalate	Water
						1
					15	
					15	
						0·5
					7·5	
				5		
				5		
					12	0·5
					4	

s et dynamites, Arendonck
et Produits chimiques, St. Martin de Crau
de Carnelle, Châtelet
s Favier, Vilvorde
s Explosifs, Cugny
Poudres de Sûreté
Dynamite, Paulilles and Ablon
ückauf" A.G., Hamburg
ngstoff A.G., Haltern and Reinsdorf

Regulation Act, 1896, and also the safety explosives in use in Belgium, France, Germany, and Austria-Hungary. In Germany the explosives are tested in certain authorised testing stations, and those answering certain requirements may be used. In the other countries they have to pass an official test.

f. **Other Means of Blasting.**—Immediately after the liquefaction of carbonic acid had been accomplished, its use in blasting operations was proposed. Apart from the old idea (which has been revived by Edison) of decomposing water in the bore-hole by electrolysis, it has been suggested that air, or liquids under high pressure, might be used.

In connection with similar suggestions, it must be remembered that there is, in practical work, a limit to the production of high pressures, and that the highest pressure practicable is, in the case of rock of medium hardness or even of very tough coal, insufficient, and that the slightest crack, or the commencement of the breaking down, will almost entirely counteract all efforts to keep up the pressure. The sudden development of high pressure, which is an essential in blasting, is well-nigh impossible by these means, as one very important faotor—namely, heat—is absent. A careful consideration of these and similar proposals will show that there is little prospect of any of them developing into a practical method of working. Some time ago, considerable attention was given to the suggestion of using lime for blasting operations. Cartridges of quicklime were placed into large bore-holes, a perforated tube inserted, and the hole well tamped. Water was then forced in through the tube by means of a pump. The swelling caused by the quicklime being slacked detached the coal. The small force thus obtainable from the very beginning limited the use of this method to the winning of coal. Even this limited field, however, was further reduced by the fact that only in hard, unfissured coal, and where the ends were large, could lime cartridges be used. The better yield in lump coal was also partly counterbalanced by its bad appearance, due to the smearing with the lime-wash produced, which made it difficult to sell.

Dr. Kosmann suggested a similar process. Sulphuric acid and zinc, in a double-chambered bottle, was to be introduced into the bore-hole, and the bottle broken by means of an iron rod. The hydrogen liberated by the reaction between the sulphuric acid and the zinc was supposed to set up sufficient pressure to break down the coal.

Some time ago a great stir was made with blasting experiments by means of liquid air. Since it has been possible, chiefly through the work of Hampson in London and Linde in Munich, to make liquid air at a cheap price, it offered great attraction for use as an explosive. It could not be used alone, but had to be mixed with some carbonaceous matter—tar-oils, paraffin wax, and charcoal being used. Experiments on a large scale, which were continued for some time in the Simplon Tunnel, showed, however, that the idea was almost unworkable. The cartridges could not be sealed up, because the slightest rise of temperature created dangerous pressures. They had to be of a very large diameter—4 inches or more—otherwise the evaporation of air made them useless. The explosion had to be initiated with a primer of guncotton and a detonator, and in order to obtain a good result the more dangerous tar-oils had to be used. Finally, the preparation of the absorbing mixture and the soaking with liquid air had to be done a few minutes before firing in the heading itself. The whole was thus rendered a dangerous and cumbersome practice. It is no wonder, then, that liquid air did not have a long life as an explosive.

g. **Mechanical Methods.**—Of late years the mechanical breaking down of coal has again come to the fore. Most machines for this purpose are based on the action of the wedge.

Dubois-François' Method.—Bore-holes are made by air-drills. The borer is then replaced by a special hammer-head, and a large wedge driven into the hole by the air-drill used as a power-hammer.

Levet's Method.—A specially constructed wedge, consisting of several parts, is inserted into the bore-hole. The several parts are then forced

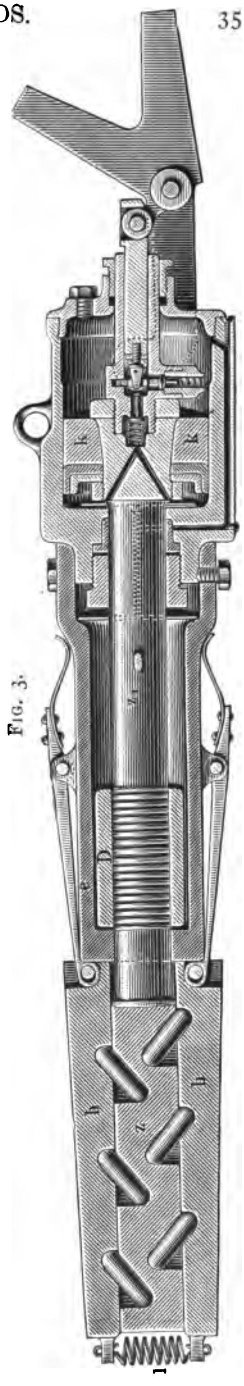


FIG. 3.

outwards against the sides of the hole by hydraulic pressure.

Walcher's Coal-breaking Apparatus (Fig. 3) is a better application of this principle. It consists of a wedge formed of two jaws, *b b*, and a centre-piece, *z*.

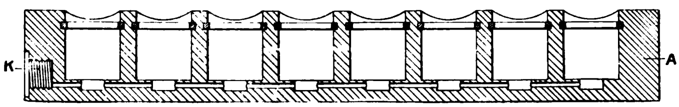


FIG. 4.

These are connected by several thrust-pins. The centre-piece, *z*, is attached to a connecting rod, z_1, having its outer end attached to the piston, *k*, of a small hydraulic press. Glycerine is forced from the outer end of the cylinder to the inner end, by means of a small force-

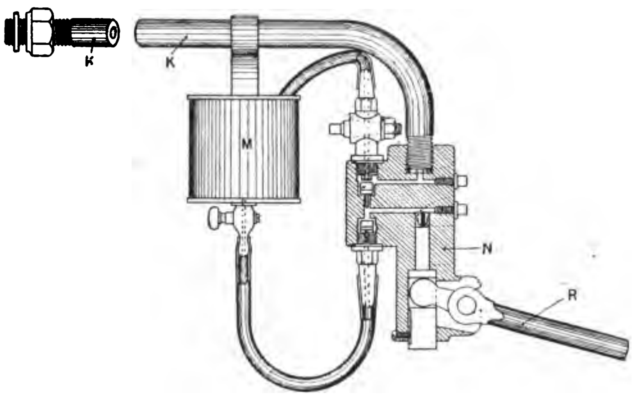


FIG. 4A.

pump attached to the cylinder, and worked by a bell-crank lever; this, forcing the piston towards the outer end of the cylinder, causes the centre-piece to recede. The thrust-pins—forming toggle-joints, from their position—force the two jaws outwards, under a constantly increasing pressure. After the coal is broken down, the machine is moved forward for a second stroke. Such appliances as these require very large bore-holes, and the coal must be cut away on both sides and on the bottom to allow of its breaking away; but even then, if the coal is either too hard, or too soft, it cannot be favourably worked in this manner.

The best appliance of this kind is the "Hydraulic

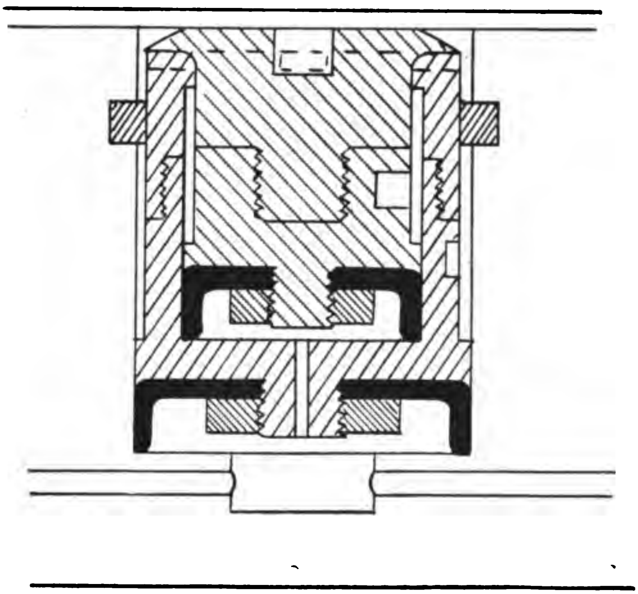


FIG. 4B.

Mining Cartridge," the invention of Mr. James Tonge of Bolton, which obtained in 1902 the Shaw prize of the Society of Arts. The coal is undercut in the usual way, the "sprags" are left in place, and then a hole $3\frac{1}{4}$ ins. diameter is drilled about 3 or 4 feet deep, until it nearly reaches the depth of holing, after which the "cartridge" is inserted. This consists of a steel cylinder (Fig. 4) 20 ins. long by 3 ins. diameter, which is connected by means of a pipe, K, to an hydraulic pump, N. This is fed from a water-tank, M, and actuated by means of a handle, R, and, after the pressure has reached a certain point, by means of an extension handle. Eight small duplex rams, which are shown in full size in fig. 4B, are fitted radially along the cylinder, A, and forced out by the hydraulic pressure, whilst thin liners prevent the rams from cutting into the coal. After the back portion of the coal is broken off, the sprags are slackened, and then the front breaks off. The whole operation takes about ten minutes. It is claimed by the inventor that a pressure of 60 tons can be exerted by this instrument, which is sufficient for ordinary coal-getting, and that there is about 25 per cent. more round coal obtained.

CHAPTER III.

QUALITIES AND HANDLING OF EXPLOSIVES.

Nature of Explosions.—An explosion is usually brought about by igniting the explosive, but it is by no means always identical with combustion. On the contrary, according to a theory first stated by Sir Frederick Abel, explosion must be considered to be the result of a great number of molecular vibrations, which are set up either by a pressure suddenly applied, by heat, or by both combined. The explosion is quicker the greater the number of vibrations in a unit of time, and the effect greater the higher the temperature produced and the greater the quantity of gas liberated, since the expansive force of the latter is proportional to the heat produced. An explosion has its greatest effect when the vibrations, the heat, and the quantity of gas reach their maximum at the same instant.

Here may be mentioned some of the most striking cases of explosion.

Nitrogen chloride explodes when thrown into boiling water. If a small piece of paper be smeared with nitrogen iodide (the temperature of explosion of which is 212° F.) and allowed to fall freely from a height of about three feet, it will explode on touching the ground. Or if it be placed on a bass violin, and the E chord struck, it is not affected; but if the G chord is struck, which gives over sixty vibrations per second, it explodes.

When a gunpowder mixture is ignited in a tamped bore-hole, it first burns away in layers, until the heat and pressure of gas become sufficient to cause explosion. If dynamite be treated in the same way it will generally burn away without detonating.

If placed on an anvil and struck sharply at an angle (*i.e.* with a glancing blow) then all the explosives employed in practice will detonate. Dynamite explodes between steel and steel when 5.63 foot-pounds (0.78 kilogrammètres) of work are done upon it; gunpowder requires 56 foot-pounds (7.75 kg.-m.) to detonate it, but whereas the explosion travels through the whole of the gunpowder, dynamite, as a rule, only detonates at the part actually struck. If a dynamite cartridge be exploded on the top of a charge of gun-cotton, the latter will merely burn away; but if the positions are reversed and the gun-cotton exploded, the detonation of the dynamite is a practical certainty.

For each explosive there is a certain temperature beyond which it cannot be suddenly heated without detonation taking place. This temperature is, for instance, 212° F. for nitrogen iodide, 356°–363° F. on an average for nitro-compounds, and 518°–608° F. for gunpowder and similar mixtures.

All this shows that explosion cannot be considered merely as combustion, nor that it can be started by ignition alone, and that, as will be shown later, the circumstances under which an explosion may be caused require very careful consideration.

Importance of Uniform Mixture.—It is an important condition with all explosives compounded of several materials, that the constituents be thoroughly incorporated; they must be so intimately mixed that, at the moment of exploding, the reaction between the various components shall take place uniformly throughout the whole mass, the actual reaction, of course, varying with the composition. If the mixture be unequal, then the reaction, and its effect, will also be different in different parts of the mass, and the total effect bad.

This is why so many powder mixtures give inferior effects, and why some brands of dynamite give such unequal results at different times. It follows from the necessity of thorough incorporation that the individual ingredients should be pulverised as finely as possible. Powders, in which the various ingredients can be distinguished by the naked eye, will invariably give bad results, and all crudely made blasting materials will give off foul and injurious gases, of which carbon monoxide is the worst.

It often happens, especially in imperfectly ventilated ends, that workmen going to the face shortly after a blast, become semi-conscious, or fall into a kind of stupor. These effects indicate, as a rule, some defect in the explosive used. With good explosives it is always possible to return to the face shortly after a blast without inconvenience—that is, after one has become accustomed to the fumes. In cases where the ventilation has not been sufficient to take away the gases at the working face after a blast, the practice of blowing in compressed air has been resorted to with success.

Handling.—As mentioned above, all blasting materials explode if struck between iron and iron; brass causes explosion less frequently, stone very seldom, and wood practically never. Boxes of dynamite have been thrown from a height of over 300 feet into quarries without any explosion taking place, though the cartridges were all crushed together into a shapeless mass.

Certain powders containing cellulose will stand very hard blows, and have hence been called "non-dangerous" or "non-explosive." The manufacturers have even recommended that they should be strongly tamped into the bore-hole with iron bars. Such advertisements as these have to be carefully guarded against. There have been cases with every explosive in which they exploded whilst being driven home with a hammer and a *wooden* tamping bar. If powder mixtures are tamped with iron or metal bars, it is quite possible to strike sparks from the rock; and if the mixture burns, however slowly, damage to the workmen is nearly sure to occur.

With dynamite it is sometimes observed that the cartridges are greasy to the touch, or even that visible drops of nitro-glycerine have exuded. This usually indicates the use of bad absorbents, or over-saturation in manufacture. If such dynamite cannot be rejected, the best plan is to absorb the exuded nitro-glycerine with sawdust—which must be burned in the manner afterwards explained—thereby making the cartridges dry again.

This exudation sometimes happens with the best dynamites if they are stored in places exposed to the sun and badly ventilated, conditions which should be always avoided. The simplest way to ascertain if drops of liquid on a dynamite cartridge are exuded nitro-glycerine, is to absorb a drop with blotting-paper, and then strike this with a hammer on an anvil; if it detonates, it is evident that it is nitro-glycerine.

Sometimes, on the other hand, dynamite is "too dry"—*i.e.* it contains less nitro-glycerine than the absorbent is capable of holding. The effect of this is to cause only partial explosion in the bore-hole, when, if the remainder simply burns away, as it usually does in such cases, very foul gases will be given off. Similarly, blasting gelatine is sometimes as hard as horn, and then cannot be properly exploded by means of a detonator of usual strength. This is due to an excess of nitro-cellulose used for gelatinisation, which process becoming completed during storage, renders the originally soft gelatine hard.

If certain dynamites containing nitrates are stored in a damp place, and if their wrappers are made of parchment paper, a kind of endosmose takes place. The moisture from the air is absorbed, and the nitrate exuding is deposited on the outside in fur-like crystals. If such dynamite is wrapped in paraffined paper, but not tightly enough, then a solution of the nitrate is formed inside the wrapper. If this happens, the cartridges should be dried by spreading them out singly on a table covered with blotting-paper in a moderately warmed and well-ventilated room.

As nitro-glycerine is practically insoluble in water, it might be supposed that dynamite could be kept under water. Blasting gelatine, as a matter of fact, can be so kept without alteration. Kieselguhr dynamite, in parchment-paper wrappers, is very little altered by submersion under water for an hour, but if kept there longer the nitro-glycerine exudes, and in time is completely replaced by water. Other forms of dynamite become quite useless by the dissolving out of the nitrate. Careful wrapping in paraffined paper protects dynamite fairly well, especially in the case of the water-tight cartridge (*cartouche étanche*). For larger operations under water, boxes of paraffined cardboard or tin, having removable lids, are generally used (Fig. 5). The box is made water-tight by luting the lid with tallow, or some composition, a few of which are described further on.

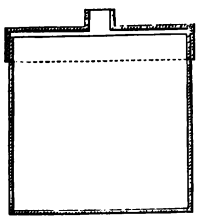


Fig. 5.

Nitro-glycerine freezes at 54° F. into long opaque crystals, the freezing considerably modifying its properties.

According to *Beckerhinn*, nitro-glycerine, when liquid, has a specific gravity of 1.599, and when frozen, of 1.735. In freezing, nitro-glycerine contracts $\frac{10}{121}$ of its volume. Whilst liquid, nitro-glycerine explodes under a blow of 5.63 foot-pounds (0.78 kg.-m.), but it requires a blow of 15.385 foot-pounds (2.13 kg.-m.) to explode it when frozen. The nitro-glycerine contained in dynamite requires a lower temperature to freeze it (depending upon the absorbent), on account of the absorbents being, as a rule, bad conductors of heat. Gelatine dynamite, for instance, does not freeze until it is cooled below 39° F.

It frequently happens that dynamite may be exposed for days to a temperature far below 32° F. without freezing, on account of the weak heat-conducting power of the absorbent, while, on the other hand, it may take several days to thaw frozen dynamite completely. Frozen dynamite becomes hard, and, in consequence of the contraction of the nitro-glycerine, there is a layer of dry kieselguhr left outside. When frozen, it cannot be exploded in the ordinary way; but it is believed that in breaking crystals of frozen nitro-glycerine some peculiar molecular action takes place, and that some accidental explosions have been thus brought about. Blasting gelatine and gelatine dynamite become opaque and hard on freezing, and are more sensitive in this state than when soft. An accident in the Nantymwyn mine is believed to have occurred through a case of frozen gelignite having been sent down an incline somewhat incautiously. Frozen blasting gelatine explodes readily enough with a detonator, but it should not, however, be rammed down a bore-hole.

If a little gun-cotton saturated with nitro-glycerine be detonated on the top of frozen dynamite, the latter will readily explode; but as gun-cotton is not always available, frozen dynamite generally has to be thawed. This is best done in special "warming-pans" (Figs 6 to 8). They consist of two zinc vessels, one inside the other, the interspace being filled with hot water having a temperature under 158° F. to supply the heat for thawing. In order to maintain the temperature the whole apparatus is sometimes placed in a double-walled box, the space between the walls being filled with sawdust, or some other non-conductor of heat. Where such an apparatus is not available, any covered vessel, placed in warm dung, may be used; but in this case it is necessary to carefully watch the temperature, as dung is very liable to become considerably heated. On large railway works it is convenient to build special thawing-rooms, or to provide the stores

FIG. 6.

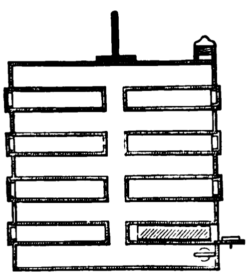


FIG. 7.

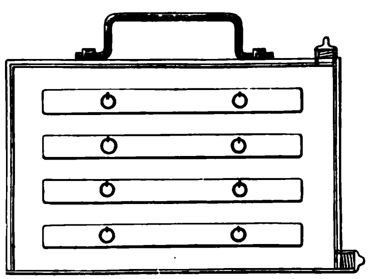


FIG. 8.

with hot-water pipes. Workmen, in order to keep the dynamite warm on its way to the place where they are going to use it, frequently carry it in their trousers pocket. In thawing dynamite great care has to be exercised, for, although the number of accidents from this cause diminish year by year, there are still people who will place vessels containing dynamite, or even the dynamite itself, on hot stoves, or near open fires, a practice that frequently leads to most disastrous results.

It should never be forgotten that nearly every explosive detonates when heated above 356° F., and that the warmer they are, the more sensitive they become to external influences.

Above 158° dynamite undergoes chemical changes, which may become very dangerous. Sudden thawing by great heat should, therefore, never be attempted. The thawing should be begun in good time and done slowly. The "warming-pans" should be cleaned with warm soda solution at least once a week, cleanliness being essential to safety. If the can leaks or wants repairing in any way, it should be previously well washed with a solution of 2 parts of caustic soda and 2 parts of alcohol to 96 of water, in order to destroy any nitro-glycerine that may have accumulated in crevices or corners.

Frequent handling of nitro-glycerine or dynamite causes violent headaches, especially if one afterwards touches the nose or tongue with the hands. There are many persons who are never affected by this physiological action of nitro-glycerine. Most people soon get inured to it, but others never. As remedies, drinking cold black coffee, the application of cold wet bandages to the back of the neck and the forehead, are usually efficacious. The use of acetate of morphia (under proper medical supervision) is also to be recommended.

All explosives do not behave in the same way when ignited. Gunpowder in small quantities simply "puffs" away, whilst larger quantities explode. The various powder mixtures behave differently, according to the care taken in manufacturing them. Some mixtures will not explode, even when large quantities of them are burnt; but, of course, it is wise always to keep gunpowder "away from fire."

Dynamite when ignited burns away slowly. At Woolwich, 225 lbs. of gelatine dynamite were burnt without any explosion occurring. Larger quantities, however, especially in a closed room, will, when ignited, develop sufficient heat to cause the remainder to explode, after part has burnt harmlessly. Therefore, should an explosives store take fire, no attempt should be made to extinguish the fire, but shelter should be sought as quickly as possible. If an explosion follows, any buildings in the immediate vicinity should be examined to see if any burning pieces have fallen upon them.

In a train of gunpowder $\frac{3}{4}$-inch diameter the explosion travels at the rate of a little over 8 feet per second, but in a train of dynamite it travels over 16,000 feet in the same time. Dynamite, however, requires a strong initial impulse to explode it, which is generally given by detonators. Gunpowder, if fired by a detonator, also develops greater force than if simply ignited; but this cannot be used in mining work, as gunpowder requires tight tamping in the bore-hole, which would be dangerous in this case.

An explosion is attended with a great development of heat, and although exact determinations are not possible for several reasons, recent experiments show that it is safe to assume for gunpowder about 3400° F., and for nitro-glycerine 5500° F., as the temperature produced by explosion.

The force developed by explosives depends naturally upon their quantity and on the duration of the explosion. According to Trauzl, 2.2 lbs. (1 kilo.) of gunpowder, occupying a cubic space of about 4 inches side (0.100 m.), develop over $1\frac{1}{2}$ million foot-pounds of energy in $\frac{1}{100}$th of a second, and the same quantity of dynamite, occupying a cubic space of only $3\frac{1}{2}$ inches side (0.090 m.), develops over $7\frac{1}{4}$ million foot-pounds of energy in $\frac{1}{50000}$th of a second.

It is essential that blasting materials should contain a minimum amount of moisture, though consumers seldom attach sufficient importance to this condition; the amount is rarely less than $\frac{1}{4}$ per cent., and the average is about $\frac{1}{2}$ per cent., as some moisture is always absorbed from the air, and considerably lessens the effect of the explosive. Blasting materials, containing 5 per cent. of moisture, lose at least a quarter of their effect, whilst the presence of from 15 to 20 per cent. prevents them being exploded at all. Gun-cotton is an exception. Even with the last-mentioned percentage of water it can still be detonated by means of a primer of dry gun-cotton.

The chemical examination of blasting materials can rarely be made by simple means, so that it is best to leave it to experienced hands. Only those who have had long practice in their analysis, and are perfectly acquainted with the properties of explosives, can obtain reliable results. Those who, nevertheless, wish to carry out such an examination, will find complete instruction in the Author's book on the "Manufacture of Explosives."

If for any reason it is necessary to destroy a quantity of explosives, it should be taken out of its packages, or, in the case of dynamite, even out of the parchment-paper wrappers. Powder mixtures, or other readily soluble materials, should be thrown into a large quantity of water. With dynamite or similar explosives, it is best to lay them out in a long train in a field, saturate them with paraffin oil and ignite by means of a safety-fuse, taking care to so arrange the train of explosive that the flame is propagated in a direction opposite to the wind. When these precautions are taken it is very seldom that there is any explosion.

CHAPTER IV.

THE CHOICE OF BLASTING MATERIALS.

THERE is, perhaps, nothing more difficult than to select the explosive most suitable for any particular purpose out of the many that are advertised. Many mines that have been working unprofitably have been made successful by changing the explosive used, but just as often great disadvantages have been caused.

In general it may be assumed that the blast should not break the rock into very small pieces. With coal it is desirable to get as large blocks as possible; ores also are usually more easily treated in the furnace when in fairly large pieces; and, if metallic veins are being worked, the production of much small stuff makes hand-picking difficult. For this reason extremely strong and quick explosives (like pure blasting gelatine, for instance) are not always the most suitable, and this is why dynamites, containing a smaller percentage of nitro-glycerine, or even direct-exploding materials which are still slower in action, are frequently used.

It might be thought that there is no necessity for the lower grades of dynamite, and that the same result would be obtained by taking a smaller quantity of a quicker and more powerful dynamite as by using a relatively large quantity of weaker dynamite. It will be shown later on that this is not true for charges in bore-holes. It may be briefly pointed out here, however, that if a blast be made with the bore-hole in the position shown in Fig. 9, where there are two free sides and a long charge, *a*, *b*, used, the rock will be broken down along the lines $a\,a_1$, $b\,b_1$. If a charge, *a c*, half the length of the other, but equally powerful, be used, the fracture will take place along *a d*, *c e*, and, consequently, a much smaller quantity of rock will be thrown down.

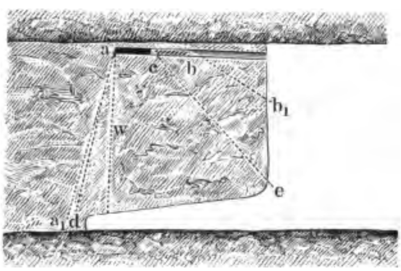


Fig. 9.

In the former case the force per unit length is sufficient to overcome the resistance *w*, but when the force per unit length is increased by taking the charge *a c*, it is more than sufficient to overcome the resistance *w*; but as it diminishes towards the sides, it cannot affect so large an area. From this it will be seen that (up to a certain limit, which is determined by the length of the line of resistance) with extended charges it is often advantageous to use bulky explosives—*i.e.* those of low specific gravity.

There are conditions which at once exclude the use of certain explosives. For instance, it is impossible to use a direct exploding material in very hard tough rocks. The bore-holes are naturally made as small and as short as possible in such rocks, and the quantity of a low explosive required for the work to be done would either necessitate larger and more expensive bore-holes, or so nearly fill small ones, that sufficient room would not be left for the tamping, which would be sure to blow out.

Very soft stone also can be worked more profitably by dynamite, because the comparatively slow action of a low explosive would be to some extent lost by the rock partly yielding, on account of its elasticity, before sufficient force was available to overcome the resistance to fracture.

It is evident that for wet bore-holes low explosives are not suitable.

There may be, of course, local conditions which will have to be considered—for instance, in some lignite mines in North-West Bohemia, dynamite is not used, on account of its covering the coal with a fine reddish dust after blasting; this affects its selling price, as it ought to look jet black. In the Aschersleben salt-mines, gunpowder cannot be used, as the products of combustion, in conjunction with the salt dust, seriously affect the eyes of the miners. In coal-mines, blasting-powder or similar explosives are often preferred, as it breaks down the coal in larger blocks which fetch a higher price per ton than smaller stuff.

Although the judicious use of weaker dynamites shows that they present the same advantages, there is still much disagreement as to which is the best explosive for coal-mining, as experiments in different mines have, by reason of the conditions not being the same, given different results.

Without fear of being accused of partiality, it can be said that, at the present day, dynamites, taking them all round, fulfil the various requirements of strength, safety, handiness, and economy in working, better than any of their competitors, and for all works on a large scale they are now almost exclusively used. Local considerations may make the use of other explosives preferable, and it has then to be found by experiments which is the most suitable.

A by no means unimportant factor in deciding on what blasting agent it is best to use, is how to meet the prejudices of the workmen, who, as a rule, view every new explosive with distrust, partly because they are unaccustomed to the manner in which it has to be used, and partly because they fear it may affect their earnings, by its giving an inferior effect, or that the contract price will be reduced if the yield is better. As the workmen generally pay for the explosives they use, some employers do not think it advisable to interfere with the men's choice. This, to a certain extent, is right; still, every judicious manager will carefully control the quality and quantity of explosive used, since the amount of work done, and the quality of the material gained, depend largely upon these points.

It may even happen that the men will have to be forced to use a new but more suitable explosive, and it will then depend largely upon the manager's tact and careful superintendence whether an improvement is effected or not.

APPARATUS FOR MEASURING THE FORCE OF EXPLOSIVES.

Attempts at examining the effects of explosives by simple means date back almost to their invention. Though there is no lack of contrivances for determining the fitness of explosives for use in firearms—such properties, for instance, as their propelling power, stability, sensitiveness to shock, deterioration when stored, etc.—there is as yet no satisfactory apparatus by which a comparison of the strength of all explosives one against the other can be made.

For blasting work the chief consideration is the force of the explosive. This is directly proportional to the quantity of gas developed and the heat liberated, and inversely to the time occupied in the production of the gases. The various rack bar, pendulum and other tests only show the quickness of the explosive, and not its strength.

It is essential, with any apparatus for determining the strength of an explosive, that the material under examination shall detonate completely in it before the gases can escape, and that as small a quantity as possible shall be able to escape through the fuse opening, or in any other way. The two apparatus that have hitherto proved best, and have been most extensively used, are the author's "force measurer" for low explosives (gunpowder and similar mixtures), and Trauzl's "lead-block test" for high explosives (dynamite, etc.).

Guttmann's Force Measurer.—This is shown in section in Fig. 10. It consists of a centre-piece, *a*, and two end-pieces, *b b*, all three being made of hardened Bessemer steel. The end-pieces fit over the screwed projections on *a*, the centre-piece has an axial cylindrical hole 35 mm. (1.38 inches) in diameter bored through it. The hole in the end-pieces is of the same diameter on the inside, but is tapered for a

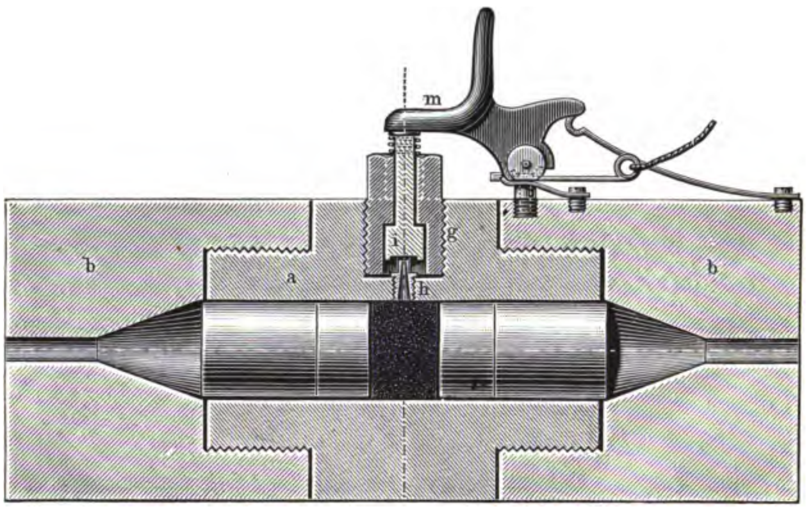


FIG. 10.

length of 35 mm., when it becomes cylindrical, but reduced to 10 mm. (0.39 inch) diameter. At the top and on the centre line of *a* is the firing-plug, *g*; this is screwed in to a depth of 25 mm. (0.98 inch); at the lower end of this recess is the firing-nipple, *h*, to take the detonating cap; the firing-plug, *g*, is perforated with a 6 mm. (0.24 inch) hole, and is chambered out at its lower end to fit over the nipple, *h*; *g* is fitted with the sliding piece, *i*, which serves the double purpose of transmitting the blow of the hammer into the cap on *h*, and acting as a back-pressure-valve to prevent the escape of any gas after the explosion in the central chamber has taken place. The apparatus is charged by screwing off one end-piece and inserting, first, a cylinder of drawn (not cast) lead 35 mm. diameter and 40 mm. (1.51 inches) long; second, a steel disc 35 mm. diameter, whose thickness depends on the specific volume of the mixture under test, for the determination of which a special graduated vessel is supplied with the apparatus; third, a disc of cardboard ("glazing board") 1 mm. (0.04 inch) thick, which fits tightly in the central chamber of *a*; fourth, exactly 20 grammes (300 grains) of the powder to be tested; fifth, another cardboard disc; sixth, another steel disc; and last, another lead cylinder. The end-piece is then screwed on; the outside of the apparatus being hexagonal (shown in end elevation in Fig. 11), this can best be done by a strong spanner. An ordinary cap is placed on the nipple, *h*, and the hammer raised. The latter is released by a cord, and the powder fired by means of the cap. When the explosion takes place the valve, *i*, automatically lifts and prevents the escape of any of the gases produced by the explosion. Consequently the explosion takes place in a perfectly closed chamber and *no report* is heard. The steel discs are forcibly driven outwards by the explosion, and drive the lead cylinders into the conical holes in the two end-pieces. The apparatus can be immediately opened by screwing off the end-pieces, and the height of the lead cones projecting measured by a sliding gauge supplied with the apparatus (Fig. 12). This height is compared with that obtained by experimenting with some standard explosive, usually blasting powder, and gives the comparative strength. Less exact results would be obtained if the cavity produced were measured, as the original volume of the powder would have to be deducted, and this cannot be readily determined with exactness on account of the screwing on of the end compressing the powder somewhat.

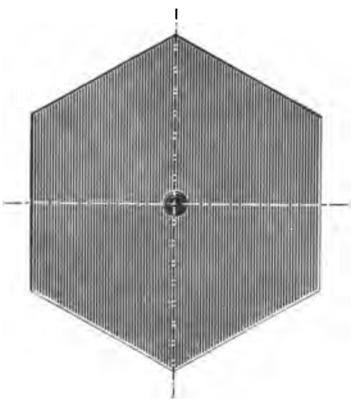


FIG. 11.

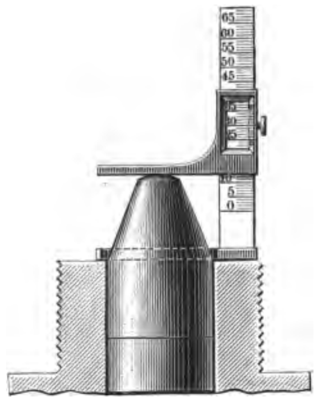
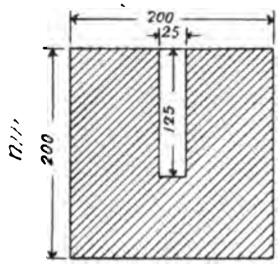


FIG. 12.

This apparatus gives very exact results, as is shown by the fact that powders of the same composition, but having differently sized grains, which give the same results in bore-holes, also give the same height of cone in the author's apparatus, but give different results, one from the other, in any other apparatus.

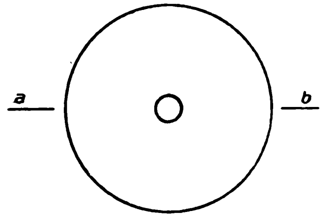
Trauzl's "Lead-block Test."—This method, which is used for high explosives or indirect exploding materials, such as dynamite, etc., is now in general use. The blocks are prepared in the following manner, which has been regulated by the International Congress of

Applied Chemistry held in Berlin in 1903. They should be made from refined soft lead as pure as possible, and



Section *a b*.

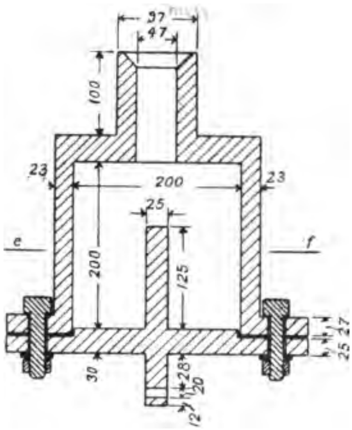
FIG. 13.



Plan.

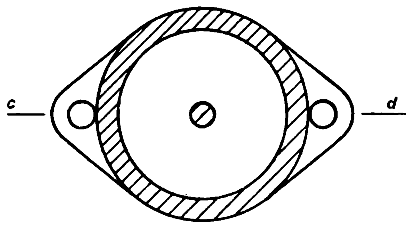
FIG. 14.

the cylinders used for a series of tests should be taken from one smelting operation. The mould for casting the cylinders is shown in Figs. 15 and 16. To heat



Section *c d*.

FIG. 15.



Section *e f*.

FIG. 16.

the casting funnel, a red-hot iron ring is to be laid round it. After casting, the lead cylinders (Figs. 13 and 14) should stand long enough to acquire a temperature of 15° to 20° C. throughout.

Ten grms. of explosive are weighed and made into a cartridge of 25 mm. diameter by means of tinfoil weighing 80 to 100 grms. per sq. m., and cut to the dimensions in Fig. 17. The shot is fired electrically only, using a 2-grm. detonator inserted into the centre of the explosive. The cartridge is brought down to the hole by means of a wooden stick and gently pressed, whilst the wires are held in the centre of the hole. The shot is tamped with thoroughly dried quartz sand, which has passed a sieve of 144 meshes per sq. cm., the wire being 0.35 mm. thick. The sand

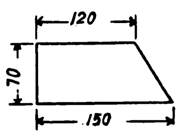


FIG. 17.

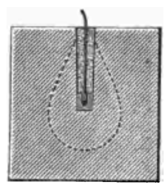


FIG. 18.

is run in uniformly until the hole is completely filled, and any excess is smoothed off. After firing, the lead block is turned upside down and any residue is brushed out. The cavity produced is gauged by means of water, and the number of c.c. used, less those for the original hole, measures the effect of the explosive.

Theoretically, a spherical cavity ought to be produced by the explosion; but as some gases escape through the channel left by the fuse, and as the resistance of the tamping is less than that of the lead, the actual cavity produced is pear-shaped (shown in Fig. 18 by the dotted line). The volume of this cavity, which is measured by filling it with water from a graduated vessel, is a measure of the explosive. As the hardness of lead varies, and is increased by remelting, it is advisable to keep in stock a number of lead blocks cast from one melting, and when trying an explosive to try the standard of the one it is to be compared with—usually kieselguhr dynamite containing 75 per cent. of nitro-glycerine—at the same time. It should be borne in mind, however, that a proper comparison can only be made in this lead-block test between such explosives as do not differ very widely in their properties. Thus, aluminium explosives show in the lead-block test an apparently much greater force than they actually possess, the reason being the abnormally high temperature of explosion, which seems to affect the properties of the lead.

The test used in the Home Office testing station at Woolwich for comparing the strength of explosives is based upon the well-known ballistic pendulum, and is singularly reliable. On account of its large size and cost, however, it is scarcely one that would be convenient to consumers of explosives. The explosive is charged into a mortar, which is run against another "gun" hung pendulum-like on roller bearings. On firing the charge, the force of the explosion causes the gun to swing, and the amount of swing, measured in inches, is shown on a sliding-scale set at the zero-mark before firing.

In Austria-Hungary an apparatus is used (Fig. 19) which is based on the deformation of lead cylinders. A cast-iron plate, P, has a small circular cavity into which two lead cylinders, Z Z (40 mm. diameter and 30 mm. high), are placed one above the other. On the top of these are laid one or two steel discs 4.5 mm. thick, and then the charge of 50 grms. contained in a cylindrical tin 40 mm. diameter and 30 mm. high inside, the thickness of the metal being 0.5 mm. A tin lid, with a small cylindrical projection to take the cap and fuse, fits tightly into the case. Ecrasite (a picric acid explosive) crushes the upper cylinder by 24 to 27 mm., the lower one by 11 to 11.1 mm. For Wetter dynamite (a safety explosive) the figures are respectively 12 and 4.5 mm.

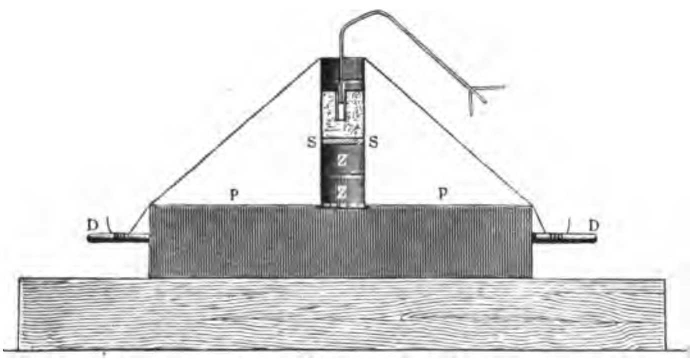


FIG. 19.

Although these apparatus give very valuable assistance in judging explosives, the reader is warned against relying upon them entirely for drawing *absolute* conclusions as to the suitability of various explosives for any specific purpose. The circumstances attending blasting in rock vary so much, and the requirements are so various in different places, that a decisive opinion can only be formed by a trial extending over several days, made in precisely equal workings, and after careful calculation and consideration of all the advantages and disadvantages.

BLASTING IN FIERY MINES.

The fire-damp present in many coal-mines causes a large yearly loss of life. The cause of its exploding is almost always due to one of three things—the use of defective safety-lamps, carelessness on the part of the miners in using naked lights, or from blasting operations. The proper means of combating the first two causes are the subject of serious study on the part of experts, and do not fall within the scope of this book; the last cause only will be briefly considered here.

Fire-damp is a mixture of methane (carburetted hydrogen gas CH_4) with at least six times its volume of air. Experience has shown that a mixture of about 9½ per cent. of methane and air explodes most violently. In mixtures containing less than 5 per cent. and more than 14 per cent. the flame is not propagated, but these are none the less dangerous. Thus, although pockets of gas in the coal-seam itself cannot be fired by a blast, the gas issuing therefrom, on mixing with the air in the workings, immediately becomes dangerous. Coal-dust in "dusty" mines is also highly explosive, and fire-damp with a low percentage of methane becomes explosive when mixed with coal-dust.

An explosion of fire-damp may be caused (*a*) by firing the shot by means of fuses, etc.; (*b*) by part of the unexploded explosive being blown out whilst still burning; or (*c*) by a communication being opened between the detonating explosive and the air in the mine. The precautions required in each case are evident.

Firing a shot by means of a fuse or any means that can produce a flame is now prohibited everywhere. Electrical firing, if properly installed and attended to, is quite safe, and so are Lauer's friction fuse and Tirmann's percussion fuse, and probably also Hess' detonating fuse. To prevent part of the burning explosive being blown out, the hole should not be overcharged, and there should be proper stemming. In this country special care is taken, when testing explosives before placing them on the "permitted list," to see that they explode completely. Communication between the exploding charge and the air of the mine only occurs when the bore-hole crosses a natural fissure or crack, when the tamping has been insufficient or along the aperture formed by the fuse. Consequently, if bore-holes are driven with care, are properly tamped, and the charges are fired by electricity, the danger disappears. Bore-holes should never be tamped with coal-dust, but with damp clay, as the former is very liable to fire and ignite any fire-damp that may be present.

The use of gunpowder or dynamite in fiery mines is now generally prohibited, since both experience and experiments have proved them to be dangerous. The first important steps towards elucidation of the question of explosives in fiery mines were taken by the French Commission in 1887, which reported in 1888. Subsequently, a Committee of the North of England Institute of Mining Engineers carried out exhaustive experiments at Hebburn-on-Tyne, and now every interested country has both official and private testing stations. In this country all explosives for use in coal-mines must be tested at the Home Office testing station in Woolwich, and on the result of this test depends their being placed on the "permitted list." As pit-gas cannot be procured in Woolwich, the gas mixture consists of coal-gas and air, which is much more sensitive, the assumption being that an explosive, which does not explode this mixture, will not fire pit-gas. Briefly, the testing station consists of a long horizontal iron cylinder, closed at one end by a disc of paper, at the other by a "gun," which is run against it, and which is charged with a quantity of explosive corresponding in strength to a charge of 2 oz. of dynamite, a definite length of stemming being used. Twenty consecutive shots must not fire the gas mixture. On the Continent the charge is fired without stemming, and is increased until the "charge limit" which fires the gas mixture is found. This is a better plan, since it allows a comparison to be made between the degrees of safety of the various explosives.

The French Explosives Committee found that pit-gas explodes at a temperature of 650° C., but that the gases of the explosion get so much cooled, that even if the temperature of explosion rises to 2200° C. the gas is not fired. They fixed, therefore, as a standard that the calculated temperature of explosion of an explosive should not exceed 1500° C. This regulation has, however, been contested by subsequent experiments. Carbonite, for instance, which has an explosion temperature of over 1800° C., is one of the safest explosives, of which 2¼ lbs. (1000 grms.) do not fire an 8 per cent. pit-gas mixture, although 2½ lbs. (1100 grms.)

do fire it. This also shows that there is no absolutely safe explosive, each having a certain limit of safety. On the other hand, the safety of explosives cannot always be measured by their temperature of explosion. Experiments made by Mr. Bichel in Schlebusch have shown that the velocity of explosion, the heat developed, and the density of the charge, and consequently the pressure of the gases, the length and duration of the flame, all unite in reducing the safety of an explosive.

Generally speaking, mixtures of ammonium nitrate with some combustible body are reasonably safe; but also some dynamites containing such components as wood-meal, flour, etc. are very safe, since the carbonic oxide and hydrogen formed on explosion have a quenching effect on the flame in the absence of air. The explosives at present on the permitted list in this country are to be found in the table annexed to page 32, in which their composition, as well as similarly composed explosives, can be seen at a glance.

MEANS OF IGNITING CHARGES.

Although safety-fuses can be had almost anywhere, the old simple methods of ignition are still to be found in use, especially with gunpowder.

Of these the *straws* are the most generally used. They consist of undamaged straws, the knots of which are scraped thin, filled with fine grained gunpowder, and having their ends closed by pieces of paper gummed on. Pietzka, of Morgenroth, patented an apparatus for filling these straws. It consists of a frame on which the straws are clamped ; the ends are then inserted together into the mouth of a hopper, and the powder shaken in by an agitator actuated by a crank. The *linstock* is generally half a split reed, along which a paste of gunpowder and water is smeared and afterwards dried; the *rocket* is a whole reed, treated in the same way; the *quickmatch* is a piece of woollen thread dipped into a similar paste and then dried. All of these are still used. They are ignited by the *sulphur match*, which is made by dipping a piece of woollen thread into melted sulphur. It is not safe to use *touchwood boletus* to ignite charges, as it burns unequally and sometimes goes out altogether. The *lighter*, a piece of woollen thread, or even twisted paper, soaked in oil from the miner's lamp, is also very uncertain in its action.

Safety-fuses (Bickford's fuses) are undoubtedly the best means of firing a blasting charge. They are manufactured by machines, by which a number of jute threads are spun round the outlet tube of a hopper through which fine meal-powder is descending. A second row of jute threads are spun round at the same time in the opposite direction, forming a second covering. The so-called double fuses have a third layer of jute spun round them. The double fuse, with a coating of tar between the second and third coverings, can be strongly recommended, as it will resist damp for a considerable period. After it is made the fuse is either tarred, coated with whitening, or drawn through a gutta-percha solution; it is then cut into lengths of from 8 to 10 yards and rolled into coils. Unfortunately, the great competition has induced some manufacturers to use bad materials, especially sodium nitrate. It is therefore important to buy fuses only from reliable factories or merchants.

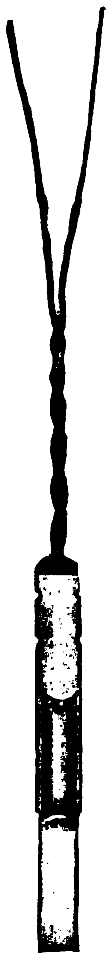


Fig. 20.

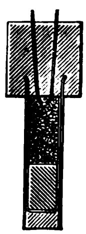


Fig. 21.

Good fuses burn at the rate of about 1 foot in 30 seconds. In burning a piece about 2 yards long, no spitting or report should be noticeable, the spark should not strike through the fuse, nor should the fuse continue to glow. Several such pieces when lighted together should burn for about the same time. High explosives, such as dynamites, are almost invariably ignited by detonators and fuses. Occasionally, in Sweden for instance, a small cartridge of sporting powder is used instead of a detonator.

Detonators are thin copper tubes closed at one end and filled with a detonating composition, consisting of fulminate of mercury, and generally potassium chlorate. The quantity varies up to 30 grains. No. 5, which contains 12 grains, is the best size for general use; No. 7, containing 22½ grains, is mostly used for safety explosives containing ammonium nitrate. Fulminate of mercury is produced by the action of nitric acid and alcohol upon mercury. Being one of the quickest explosives known, it gives an extremely sharp shock, which is exactly what is required to detonate high explosives. Fulminate of mercury is very sensitive to heat, to shocks, etc., and as the quantity contained in ordinary detonators is quite sufficient to shatter the hand, great care is essential in handling them.

Electrical detonators (slot detonators) (Figs. 20 and 21) are the same as ordinary detonators with the addition of a layer of priming mixture, which is generally made of antimony sulphide and potassium chlorate.

A plug of melted sulphur and powdered glass is moulded over a U-shaped piece of brass wire; a fine slot is then cut through the wire with a pair of pliers at the centre of the bend. The plug is then inserted into the copper casing of the detonator so that the two bent ends of the wire project into the priming mixture; it is then made tight with india-rubber solution.

General Hess uses insulated wires, so that there is no need of connecting wires outside. The conducting wires are insulated either with india-rubber, with tarred tape, or are laid in grooved sticks.

For the ignition of gunpowder, copper tubes with a priming composition, but without fulminate of mercury, are used. Other kinds of electric fuses will be dealt with later on.

Fuses should never be lit by a lamp. On large works —railway cuttings, for instance—where from thirty to forty shots are often fired simultaneously, it is obviously impossible. A slow-match should be used. It should be easily lit, burn slowly, and should not throw sparks nor deposit ashes on the still glowing parts, as the latter will seriously retard the ignition. A slow-match is best made by placing about 5 yards of tightlyplaited hemp or cotton cord for about 15 minutes in a boiling solution of .2 oz. of lead acetate to a quart of water, rinsing it out and finally drying in a shady place. A slow-match thus prepared [1] (formerly used by the French artillery) burns at the rate of about 6 inches per hour, with a conical glowing end about $\frac{3}{8}$-inch long, which will stand some pressure without falling off, and leaves no ash. In extinguishing it a little of the partly consumed end should be left on, as otherwise it is difficult to relight.

The firing arrangement suggested by General Hess, consisting of small discs of blasting gelatine, which are attached to the powder core of the fuse by fine nails, and which, when touched with a slow-match, are sure to ignite, has not been much used on account of the difficulty of conveying the disc, and the opposition of the miners to the extra expense. They sometimes smear a small quantity of dynamite on the end of the fuse, which serves the same purpose, but is objectionable, as it causes dynamite to be spilt in the mine.

[1] Désortiaux, *La Poudre, les Corps Explosifs, et la Pyrotechnie* (Paris, 1878).

CHAPTER V.

PREPARATION OF BLASTS.

1. BORE-HOLES.

a. **Manual Work.**—The manner of making bore-holes by hand with drills, with or without the use of sledge-hammers, is well known. Octagonal cast-steel bars are now most frequently used for making drills. Occasionally iron bars with hardened cutting points and heads are used. The borer with a flat chisel point (Figs. 22 and 23) is the most common form; it was first used in the Hartz mines in 1749 by Hungarian miners. Crown drills (Figs. 24 to 27) are sometimes used, but only in very soft rock.

With the chisel-borer the angle between the faces of the cutting-edge varies with the hardness of the rock it is used in; but it should not exceed 70°. Bad drills will cause a large loss in time and material; consequently, the hardening and sharpening of drills should be carefully attended to, and only the best material used. The width of the points, and, consequently, the diameter of the hole to be cut, varies with the nature of the rock, the explosive to be used, and the depth of the bore-hole.

In general the smallest drill for gunpowder is from 1 inch to $1\frac{1}{4}$ inches, and for dynamite $\frac{3}{4}$-inch to $\frac{7}{8}$-inch width of point (though $\frac{1}{2}$-inch bore-holes have been tried for the latter in Germany) for depths up to one yard ; beyond this depth the first part of the bore-hole is made with wider drills (up to 2 inches), and the

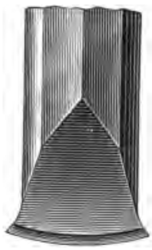


Fig. 22.

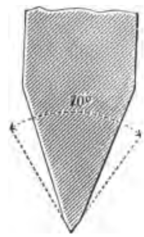


Fig. 23.

Fig. 24.

Fig. 25.

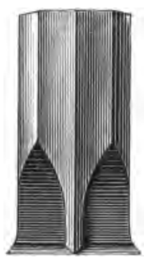


Fig. 26.

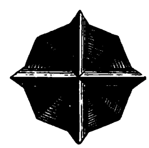


Fig. 27.

lower parts finished with narrower bars, as the depth increases. It must be remembered in drilling bore-holes, that their diameter will be rather larger than the width of the drill point. The forging and hardening of drills are manipulations requiring much skill. Care must be taken that the steel is not "burnt," and in tempering it is best to let down the steel to a bright straw yellow.

Cast-steel sledges and hammers are coming more and more into use, and are preferred, as a rule, once the miner has learnt the proper method of striking with them.

The reason some give for preferring iron sledges is that the steel ones bounce back at each stroke; but this very effect, if the striking is properly done, makes the labour lighter. The hammers vary considerably in shape. Fig. 28, in which the face is curved to a radius about equal to the length of the fore-arm, is a very commonly used form. The weight varies from $4\frac{1}{2}$ to 9 pounds.

The *sledge* (Fig. 29) is straight, and weighs at least 11 pounds; its shaft, or helve, is about 2 feet 6 inches long, and should be made of young oak or acacia, the elasticity of which makes the striking easier.

In mining work single-hand boring is most usual—that is to say, the miner manipulates both the drill and the hammer himself. In quarries and on railway work sets of two or three men usually work together, one man manipulating the drill and one or two striking with sledges. Certain miners (Italians, Americans, etc.) prefer the method of *churn drilling*, in which a long drill is swung upwards by two men or struck by sledges. With very deep bore-holes the weight of the long drill jumper is sufficient, it being lifted and thrown down by two men.

The first step in putting in a bore-hole is to flatten off the surface of the rock at the point to be drilled; a hole in the exact position and direction is then started carefully, and the strength of the blows gradually increased until the hole is deep enough to guide the drill properly. After each blow the drill is slightly lifted and turned in order to produce a round hole; this is called *setting* the drill. The dust produced by drilling must be frequently removed from the bore-hole so as not to impair the effect of the blow by cushioning. The *scraper* (Fig. 30) is used for this purpose, the large flattened end serving to scrape out the dust, and some rag or tow wrapped round the other end serves to dry the bore-hole. Whenever possible wet drilling should

FIG. 28.

FIG. 29.

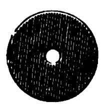


FIG. 31.

FIG. 30.

be adopted—*i.e.* water should be poured into the bore-hole, as the action of the drill is then less obstructed by the dust, and the injurious effect of the stone dust on the men's lungs is obviated. To prevent the water splashing about, straw is wound round the drill at the level of the rock, or, better still, a perforated india-rubber *washer* is used (Fig. 31). When the drilling of the bore-hole is finished it is thoroughly cleaned out and dried, and if gunpowder is going to be used it is usual to make a few more extra strokes with the drill after the cleaning out. If, from the rock being fissured or pervious, water finds its way into the bore-hole, it will have to be lined with clay. For this purpose the *dry* or *clay borer* (Fig. 32) is used. It is a plain round bar with an eye forged in it at one end through which a handle for turning it is put. If this clay-lining is still insufficient, the only way is to use waterproof cartridges.

In the case of a drill breaking the part remaining in the bore-hole is taken out with a pair of tongs (Fig. 33), or a running noose of cord is guided on to the broken

Fig. 32.

Fig. 33.

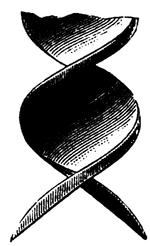


Fig. 34.

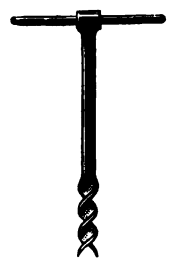


Fig. 35.

drill by a second drill, the noose pulled tight, and the broken bar drawn out.

b. **Machine-drilling.**—Special drills (Figs. 34 and 35) or *augers*, which are frequently used in mild coal, with an increase of speed and economy in working, may be considered as the first step in the transition from hand to machine drilling.

The first machine-drill, properly so called, was that invented by John Singer of Chicago.

The extensive tunnelling works that had to be executed as the large railway systems of Europe developed, gave the great impulse to the construction of machine-drills, and it is probably due to the prolonged studies of Prof. Colladon, of Geneva, on compressed air, that pneumatic drills have become a practical success in the hands of Sommeiller, Grattoni, and Grandis. The *Sommeiller drill*, which was used in the construction of the Mont Cenis tunnel, was the first one used on a large scale, and the experience gained with it formed the starting-point from which the multitude of forms at present made have been developed.

Drilling machines may be divided into two main classes; one, in which the action of the drills is percussive, and the other where it is rotary. Each of these classes may be subdivided by grouping the various drills in them as *hand* or *power* machines.

Percussive Drilling Machines.—The type of machine-drill, in which two spiral springs are compressed as the boring-bar is lifted by an eccentric cam actuated by a fly-wheel and is released at the top of the stroke so as to drive the bar forward, and in which the setting is done by the cams turning the bars, were first made by John Singer, and later in Germany and Austria. They have not been very successful on account of the blows being too weak.

As it is, for obvious reasons, impossible to describe in detail all the various patterns of rock-drills worked by compressed air, or steam, only a few, which are typical of good construction and are largely used, will be mentioned.

A mechanical rock-drill should be compact, easily manageable, and adjustable in every direction. The admission and exhaust of the compressed air, or steam, and the setting of the boring-bar, should be automatic. It should be capable of powerful action, be strongly built, and have as few moving and delicate parts as possible. A hand-feeding motion is preferred by many.

The "Sergeant" rock-drill may be taken as typical of those having slide-valves, as developed from the Burleigh drill. Lately the makers (The Ingersoll-Sergeant Rock Drill Company) have added to it an auxiliary valve, so as to admit of a variable stroke. The working of this "Sergeant" auxiliary valve drill will be easily seen from Fig. 36. A piston carrying the boring-bar moves in a cylinder. The piston is recessed in the centre. Above the piston is the valve-chest, separated from the former by a plate carrying a lug which projects into the cylinder. This lug has an arc-shaped cut milled in, in which a light curved steel piece, provided with suitable

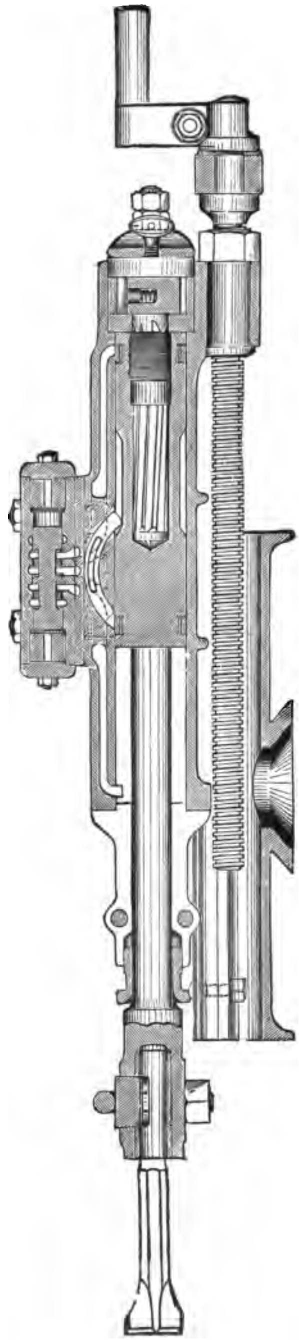


FIG. 36.

ports, slides. As the piston moves forward, the steel piece is caught by the thicker part of the piston and is thrown either forward or backward, moving the slide-valve, and thereby admitting compressed air either to the front or to the back of the piston. Inside the piston is a twisted bar with a ratchet wheel and pawl on its upper end. At every stroke this twisted bar causes the piston to slightly rotate. The feed motion for advancing the drill is effected by the long screw and crank handle.

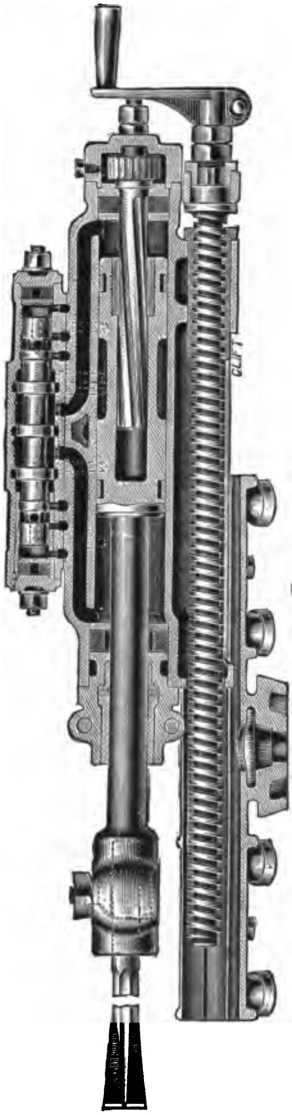


Fig. 37.

The "Daw" rock-drill (Fig. 37), made by Messrs. A. & Z. Daw of London, is of a similar design.

Of somewhat similar design is the drill made by Messrs. Holman Bros., of Camborne (Fig. 38), which is largely used. The boring-bar has two pistons, *f f*, and is swelled out between them; this swelling strikes alternately the two ends of a double tappet, which actuates the slide-valve, *n*. Similar in principle to the *Ingersoll* drill, either with or without automatic forward feed-gear, are the *Burleigh*, *Sachs*, *Rand*, *Wood*, *Allison*, *Dubois-François*, *Schramm-Mahler*, *Fröhlich*, *Cranston*, etc., drills.

The "Optimus" compound rock-drill (Ogle's patent, manufactured by Messrs. Schram, Harker & Co. of London) is shown in Fig. 39. The cylinder, *a*, has a wider portion, *a'*, and correspondingly the piston, *c*, has an enlargement, *g*. The air enters through port *b* into cylinder *a*, whilst cylinder a_1 is in communication with the air through ports *m* and *h*. As the piston moves

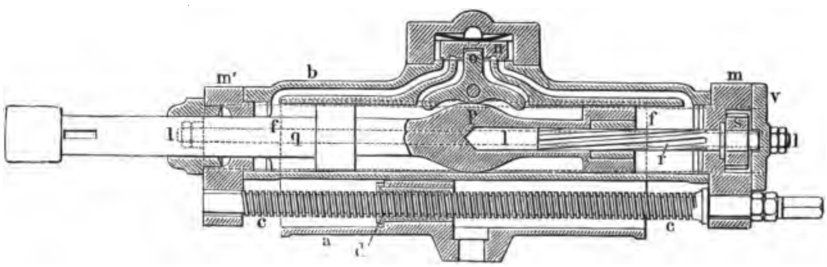


Fig. 38.

forward past the port *d*, air enters the valve-cylinder, *r*, acts there on a larger area than at *l*, and moves the valve-piston, *e*, forward, thereby cutting off communication with *a*, and making communication between *a* and a_1. The air now acts on the larger area of *g* and thereby moves the piston back, past the port *d*, when the cylinder, *r*, is placed in communication with the atmosphere through ports *d* and *h*, and the valve, *f*, is moved back.

The *Ferroux rock-drill*, manufactured by Chas. Delisle of Evian-les-Bains, which was used on the Gotthard and Arlberg tunnels, is shown in Figs. 40 to 47, Plate I. It is quite automatic in action, has

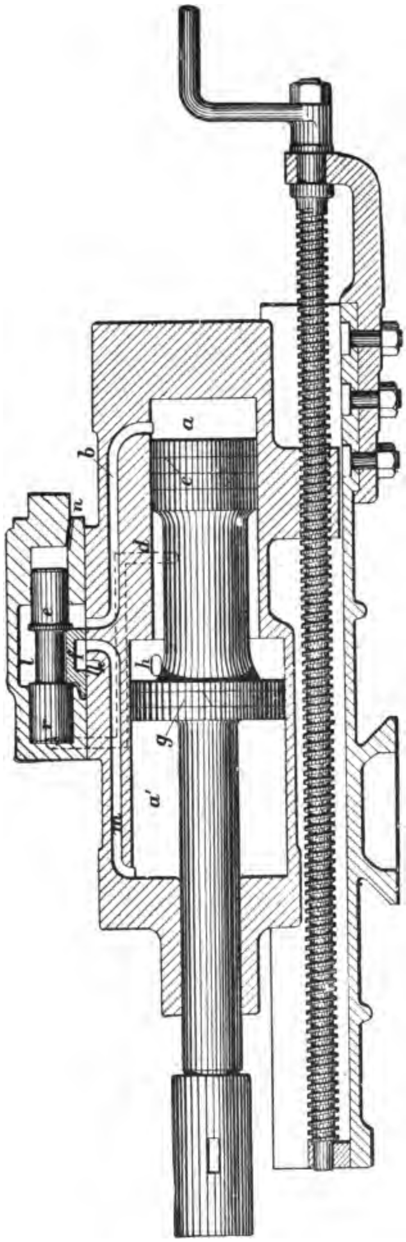


Fig. 39.

no delicate working-parts, and delivers very powerful blows. It consists of a gun-metal cylinder, C (Fig. 44), a steel piston, P, the advancing gear, B, and the setting gear, R. The air entering at *b* passes along the hollow bar, E, which is connected with the cylinder, through the air-channel, C^3 (Figs. 44 and 46), into the air-chamber, C^4. The valve, *d′*, is lifted by the coned end of the piston on the back stroke, bringing the inlet ports opposite those in C^4, and admitting compressed air into the cylinder, the exhaust ports being closed in this position of *d′*. The valve, *d*, at the other end of the cylinder is pushed down by the double lever, D,

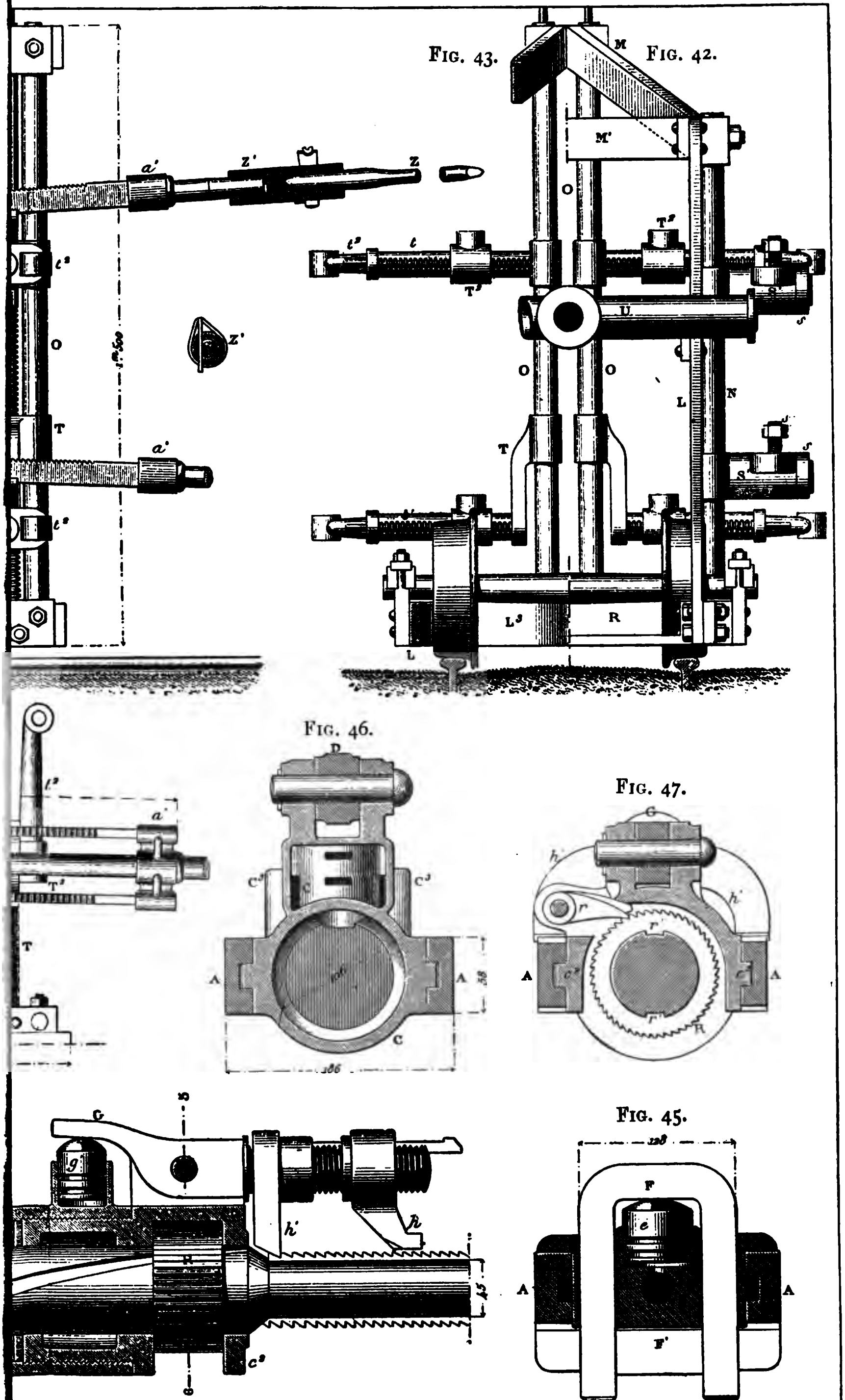


FIG. 43.
FIG. 42.
FIG. 46.
FIG. 47.
FIG. 45.
M
M'
O
T²
T³
t
t²
U
L
N
S
s
T
L²
R
a'
Z'
Z
1m.500
D
C³
A
C
186
58
G
h'
r
r'
R
g
h
c²
45
128
F
e
F'

and has its inlet ports shut and the outlet ports opened, allowing the air in the front end of the cylinder to exhaust.

As the piston makes its forward stroke the position of the valves and the motion of the piston are both reversed. The piston-rod, which is guided by the buffer, c^1, and the stuffing-box, c^2, has two helical grooves, r (Fig. 44), r_1 (Fig. 47), in which corresponding threads on the inside of the ratchet-wheel, R, engage.

The setting of the drill is done by the usual arrangement, and the advancing of the drill is accomplished automatically.

In the gun-metal cylinder, B, which is carried on the frame-bars, A A, by six bosses, slides a hollow plunger, B^1, with a piston-head on its back end, filling the bore of B. Inside B^1, there is another piston with a hollow rod, E, rigidly connected to the cylinder, C. Each outward stroke of the drill tends to force back the cylinder; this is prevented by a knife, F′ (Figs. 44 and 45), carried by a frame, F, engaging with the ratchet-rack on the lower edges of the side-frames, A (Fig. 40). A small piston, e (Fig. 44), acted on by the air-pressure, presses up F, and holds F′ firmly against these teeth. The air-pressure behind the pistons on B and B^1 constantly tends to push forward the cylinder, C, but its motion is prevented by the pawls, h' (Figs. 44 and 47), engaging in teeth on the upper edge of the side-frames, A. These pawls are carried on a swinging frame, G, one end of which is pressed upwards by a small piston, g', on the under side of which the air-pressure is acting. The other end of G carries an adjustable tappet, *h*. The pawl, *h′*, is pressed down firmly by the piston, *g′*, and the cylinder held fast until, due to the deepening of the bore-hole, the cone at the outer end of the piston-rod, P, strikes the tappet, *h*; this releases *h′*, and the cylinder is advanced one tooth along the racks in the upper sides of the frame-bars, A.

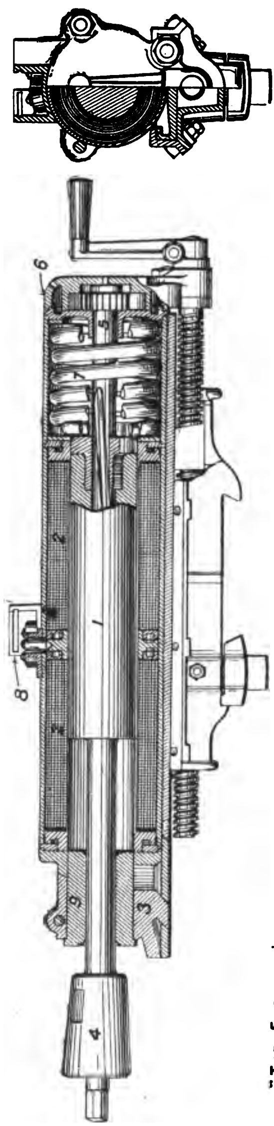


Fig. 48.
"The Engineer"

Electricity has of late years begun to play an important rôle in mining, and, consequently, it has also been adapted to rock-drills. The drill made by Siemens Brothers & Co., Lim., is really of the type of hand-drill in which the boring-bar is shot forward by a powerful spring; the movement is, of course, imparted by means of an electromotor.

A real electric drill is the Marvin-Sandycroft drill, illustrated in Fig. 48. The steel plunger (1) is surrounded by two coils of wire (2, 2), and has the usual tool-holder (4). The magnetic pull of the coils, as they are alternately excited, draws the plunger backward and forward. There is the usual rifled ratchet-rod (5) with a ratchet-wheel, and a cushion spring (7) checks the backward stroke.

An effective hand rock-drill of the revolving type is that made by the *Maschinenbau Actiengesellschaft*, of

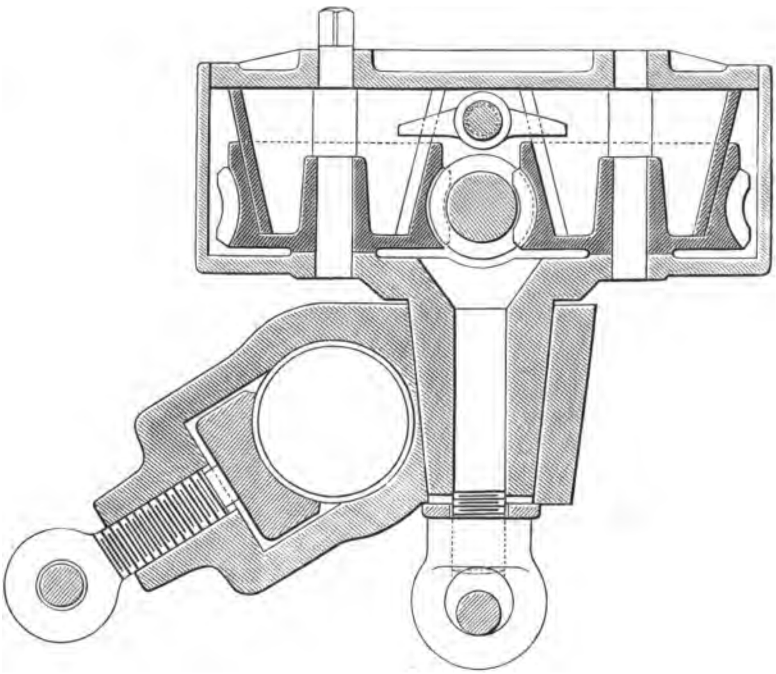


FIG. 49.

Prague (formerly Breitfeld, Daněk & Co.). It is called the *Reška drill*, and is shown in Figs. 49 to 53.

The drilling-shell is fixed to a stand (Fig. 53), and can be set in any direction by the two screws. In it are two hollow worm-wheels (Figs. 49 and 51), which act on the boring-spindle, if the expanding rings (Fig. 50) press against the worm-wheels by means of the winged cutter, which can be made wider or narrower by a screw. This determines also the velocity, eventu-

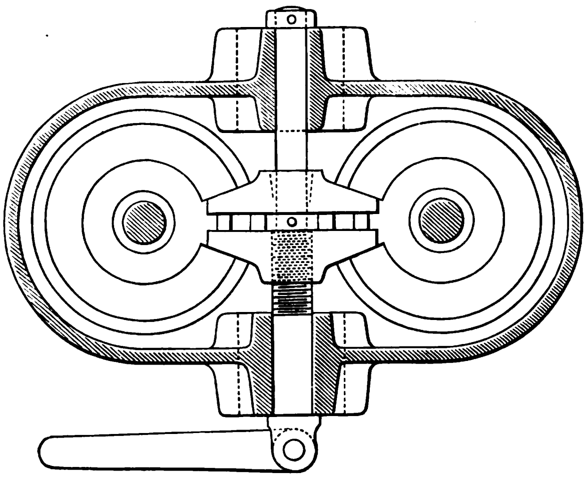


FIG. 50.

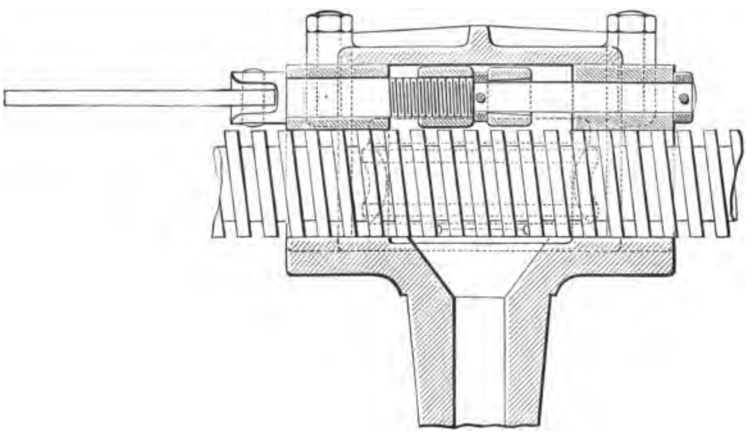
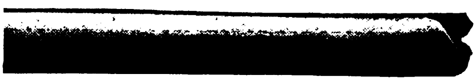


FIG. 51.

ally the firm fixing of the boring-spindle. By turning a crank handle on the axle of one of the worm-wheels the drill can be quickly taken out. The bit is a steel

[Plate II.



[To face p. 85.

spiral drill, and with its quadrangular head is simply inserted into the boring-spindle.

As a matter of course, rotary drilling by hand-power can only be employed in soft rock, such as coal, sandstone, etc., as the power available is only small; but in such rock their work is excellent, and far superior to that done by percussive drills, as the elasticity of the

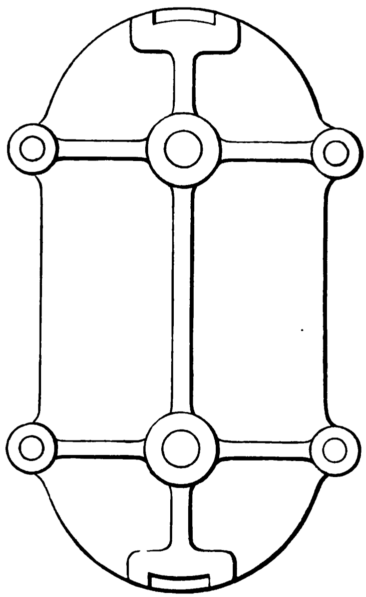


FIG. 52.

rock and the large quantity of dust produced seriously affect the efficiency of the latter.

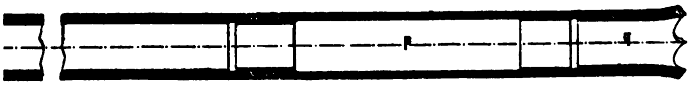
Of power-driven rotary rock-drills, the *Brandt drill*, which was employed at the St. Gotthard and Simplon tunnels, is the most prominent. It is built by Sulzer Brothers, of Winterthur, and shown in Figs. 54 and 55. The boring-bar is fixed on to the hollow ram, N, which moves along the fixed differential piston, U.

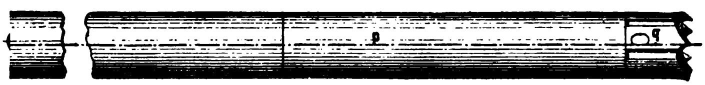
Water under pressure enters through the connection, A, into the admission chest, and through the throttle-valve, C, and the three-way cock, D, either to the back of the fixed piston, U, or into the annular chamber between N and U, thereby enabling the boring-bar to be moved forward or backward. The water escapes

FIG. 53.

through the cock, D. The boring-bar is rotated by means of two coupled cylinders, E and F, into which water enters through the cock, B. The two pistons, through the cross passages, reverse each other, and turn the worm-wheel, R, and helical wheel, S, which is mounted on the shell, T. In this way the boring-tool is rotated, and at the same time firmly pressed against the rock. Water is sent through the hollow boring-bar by means

[*Plate III.*





[*To face p.* 87.

of the tube, K, in order to cool the tool and clear the hole.

The Brandt drill worked at the Simplon with a pressure of from 1080 to 1350 lbs. per sq. in., and used from 3 to 4 pints of water per second. At each attack 7 to 12 holes, of 8 cm. diameter and 4 feet to 6 feet 8 in. depth, were drilled. The consumption of bits per hole was 4 to 7, that of dynamite 2.90 to 5.50 kgm. Each drill made on an average a hole of 1 m. depth in 24 to 58 minutes; and the time taken in each attack was, for drilling, between 2 hours and 3 hours 24 minutes, for the clearing, between 2 hours and 5 hours 12 minutes.

E. Jarolimek's rotary drill (Figs. 56 and 57, Plate III.) is built by G. Topham, of Vienna, and consists of a hollow-screwed spindle, *a*, with two keyways, *c*, cut along it; into these fit the feathers, *e*, on the bush, *d*. This bush is revolved through a worm and wheel, *g* and *h*, by a Meyer hydraulic motor, *f*, fixed to the frame. This causes the screw-spindle, to which is attached the borer, *p*, to revolve; the maximum speed being 415 revolutions per minute. A differential gear, *k*, *l*, *m*, *n*, in being keyed tight on to the nut, *o*, and *k*, having a feather key sliding in the keyways, *c*, advances the spindle, the rate of speed being adjustable. A quick withdrawing motion is provided, *l* and *n*, which are mounted on an eccentric stud, γ, and can be thrown out of gear with *k* and *m*, by turning the lever, *s*. The wheel, δ, is then lifted into gear, with the wheel, *o*, on the motor shaft, and rotates the nut, *o*, through the bevels, π ς, and the spun wheel, μ, thus screwing back *a* rapidly. Water is forced along

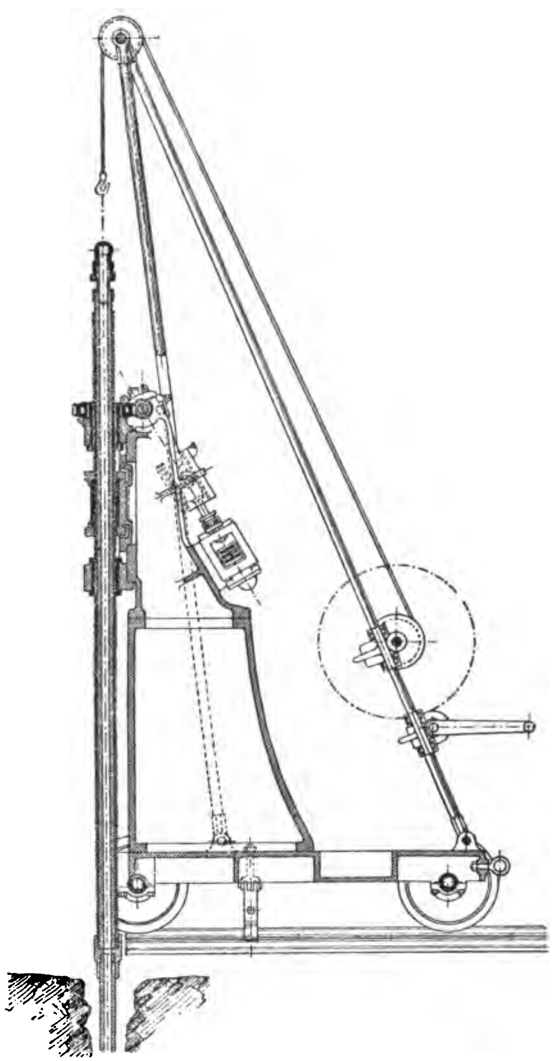


FIG. 58.

z and down the borer, *p*, into the bore-hole to keep it clear. The drill is mounted on a clamp-plate, *u*, which is secured to a column, *v*, round which it can be rotated.

A drill similar in principle, but driven by steam, was made by G. Topham for the construction of the Corinth Canal, where it was employed in drilling vertical bore-holes 200 feet deep and 3¾ inches diameter, in from 9 to 10 hours each, through solid chalk (Fig. 58).

The motive power for actuating rock-drills is usually supplied by compressed air or steam. The latter is only used in open cast workings, and but seldom in these in Europe, as there is a large loss from condensation in transmitting steam from the boilers to the drills; the construction of the latter also requires special arrangements when using steam. Compressed air has many advantages, the loss in transmission is extremely small, and the exhaust from the drills materially assists in the ventilation of underground workings.

On the St. Gotthard Tunnel works the loss of pressure was only 0.63 atmosphere through a length of 5362 metres of 0.20 and 0.15 metre pipes, the initial pressure being 5.63 atmospheres.

Descriptions of boilers and air-compressors are beyond the scope of this book, and only one example (Figs. 59 and 60) is therefore given—viz., the compressor made by *Burckhardt and Weiss*, of Bâle, which is one of the best made. It has a slide-valve on the air-cylinder, and a volume efficiency of 95 per cent.

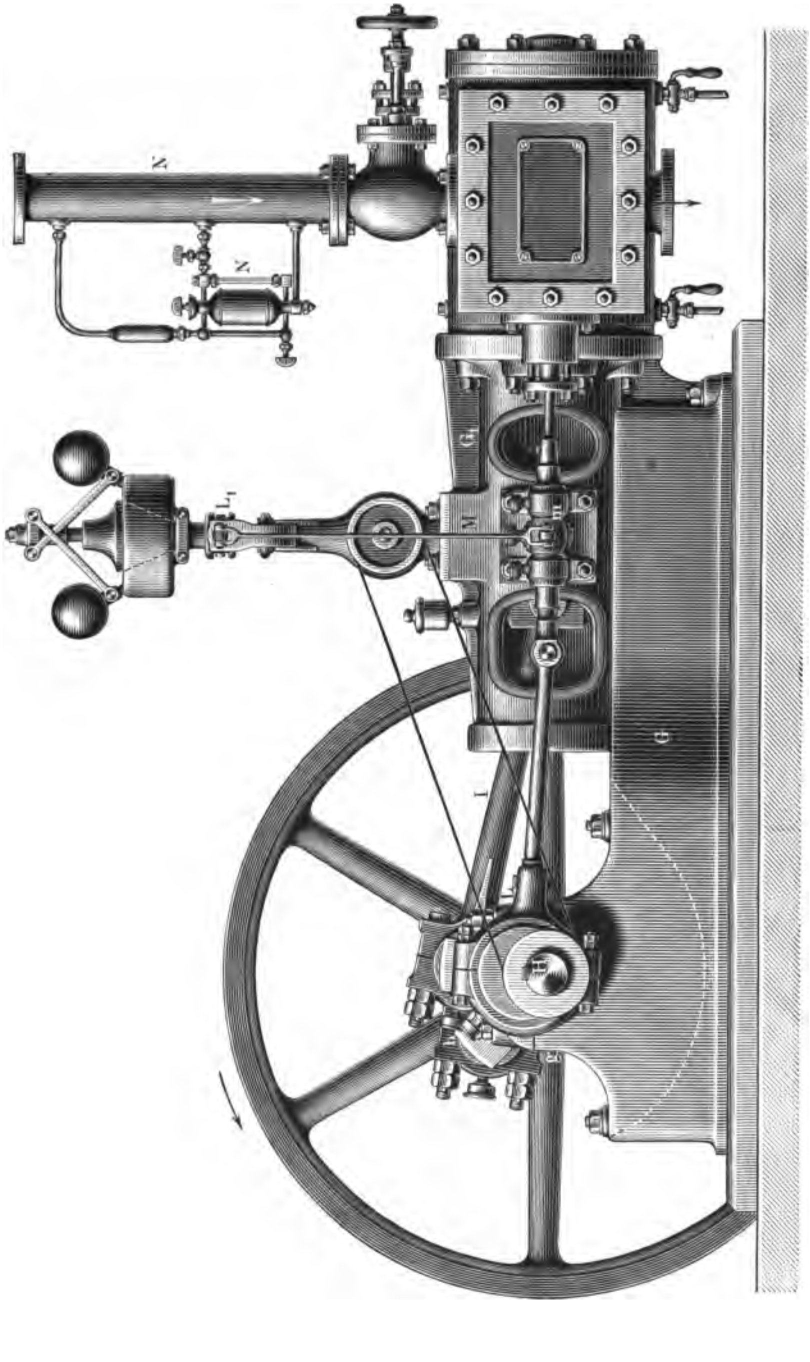


FIG. 59.

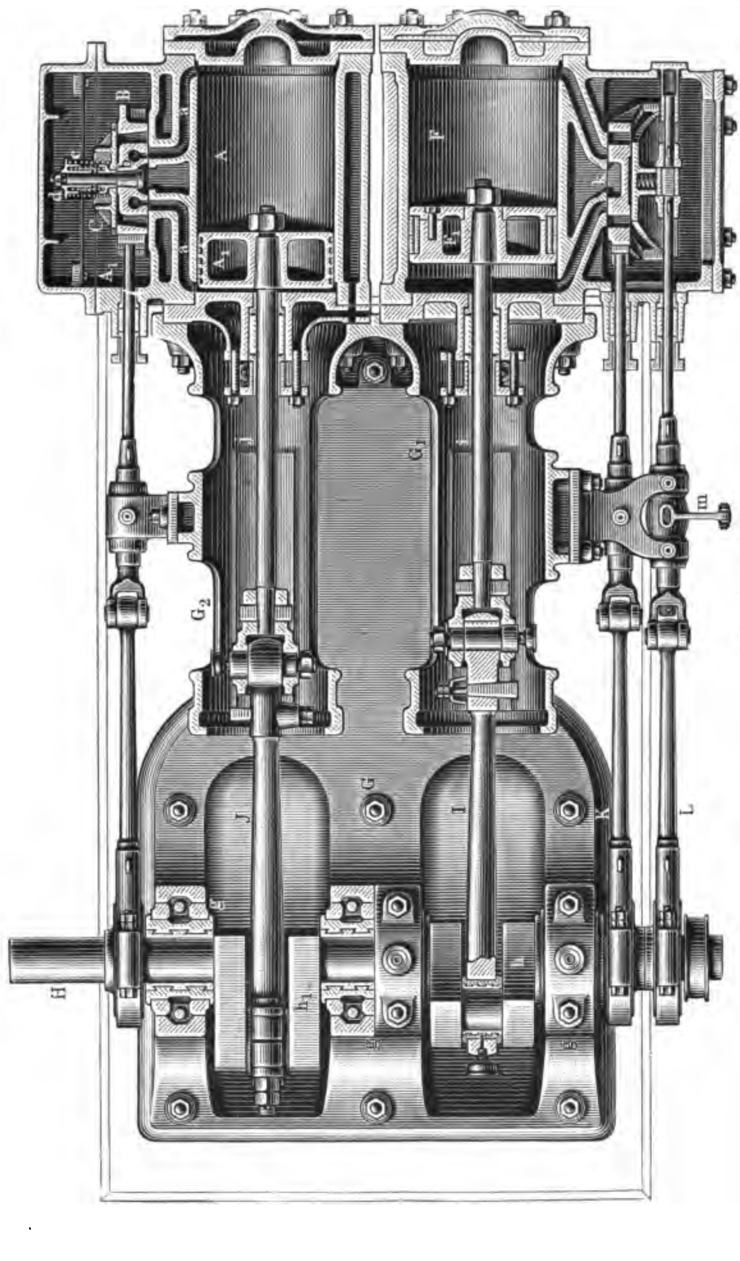


FIG. 60.

2. POSITION OF BORE-HOLES.

The proper placing of bore-holes is a very important factor in obtaining the best results from blasting shots; to do this it is, of course, necessary to have previous knowledge of the way the strata lie, the probable position of cracks or fissures in it, etc.

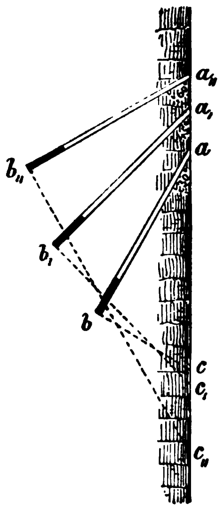


FIG. 61.

Consider first the case of blasting out from the untouched face of a rock.

Suppose a, b, $a_{\prime}$ $b_{\prime}$, $a_{\prime\prime}$ $b_{\prime\prime}$, to be three bore-holes (Fig. 61), driven respectively at 30°, 45°, and 60° with the rock face. As the line of resistance with extended charges is at right angles to the bore-hole towards the free surface, the spheres of action, b c, $b_{\prime}$ $c_{\prime}$, $b_{\prime\prime}$ $c_{\prime\prime}$, should correspond to the length of their respective bore-holes. As will be seen later, the possible line of resistance is only equal to the length of the bore-hole when the latter is put in at 45°. With the cases we are considering, the hole, a b, would not be entirely utilised, whilst $a_{\prime\prime}$ $b_{\prime\prime}$ would only throw out a small crater. It follows, therefore, that bore-holes for blasting from the untouched breast — called breaking-in shots — should not be at a greater angle than 45°.

As breaking-in shots can only have a comparatively short depth, but require a large charge, on account of the great resistance of the rock on all sides, sufficient room is not always available for the charge below the proper depth of the tamping. Therefore the angle they make with the rock face should be smaller the harder the rock.

When blasting rock with several free sides the bore-holes should be as nearly parallel with the longest free side as possible, so as to obtain the deepest bore-hole, and thus to be able to use the relatively smallest quantity of explosive.

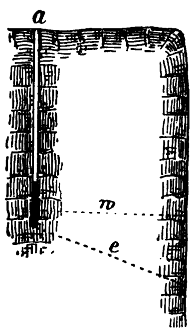


Fig. 62.

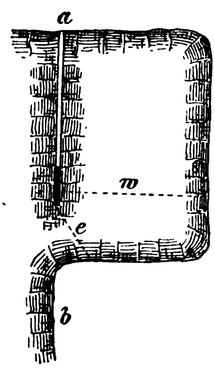


Fig. 63.

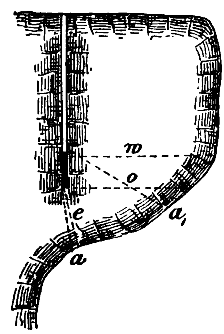


Fig. 64.

In order that the charge may be as fully utilised as possible, due regard must be given to the contour of the free sides, and the longest line of resistance.

The following are commonly occurring cases.

Vertical walls of rock with a free top (Fig. 62). The bore-hole is made vertical, so that the explosion will not have to lift the rock it breaks down, but will allow it to fall by itself, and give less work afterwards in removing; in this case w is the line of resistance, and $a\ e$, the probable crater. If the wall is holed (undercut) or otherwise free, along the base (Fig. 63), the bore-hole must be kept as far as convenient from the free base, for reasons that will be seen from the crater form of the effect which will be explained later. Ordinarily the depth of the bore-hole should be three-fourths the length of the face; it must not be behind the face of the lower part *b*, but in line with it. If the upper part of the undercutting be irregular in shape, as in Fig. 64, then the longest line at right angles to the bore-hole in the direction of the effect must be taken as the line of resistance; thus, in Fig. 64, *w* is the line of resistance to be taken, and not *o* or *e*. The charge must overcome the resistance where it is largest, if its fullest effect is to be realised. Should *e* be taken as the line of resistance (*i.e.* the shortest line of resistance), as is usually done, then the wall would not be thrown down entirely, but a crater, $a\ a_{\prime\prime}$, would be blown out.

In the present case the bore-hole can be made shorter because the charge corresponding to the face finds least resistance in the direction of the bore-hole. The effect of undercutting the base is that shorter bore-holes and correspondingly smaller charges can be used and one more free face is available, all of which are very important.

One of the most frequently occurring cases, especially in mining, is shown in Fig. 65.

Here the breast of the rock is free and it is undercut, but there is no free face above. The bore-hole has to be placed parallel to the undercutting, and should not go deeper than it, but as a rule only three-fourths to four-fifths of the depth. If the bore-hole be inclined downwards, $a\ b_{\prime\prime}$, it would have to be longer, and though the effect of the charge corresponding to w be great enough to reach towards the base, f, its effect towards e will be insufficient. If the bore-hole be continued beyond the face f, say to $b_{\prime\prime}$, the line of resistance at right angles to it falls wholly in the solid rock, and the charge, taking the shortest way, will only throw out a very disproportionate crater, $e_{\prime\prime}$ $e_{\prime\prime\prime}$, in the corner.

If the bore-hole inclines upwards, a $b_{\prime\prime\prime}$, the line of resistance is along $w_{\prime\prime\prime}$; it acts simply as a breaking-in shot, and will have only a small effect. It is clear, therefore, that the proper direction for the bore-hole is parallel to the under-cutting; and that not only should it not penetrate deeper than the free face of the latter, but it should, as a rule, be 20 to 25 per cent. shorter, according to the hardness of the rock.

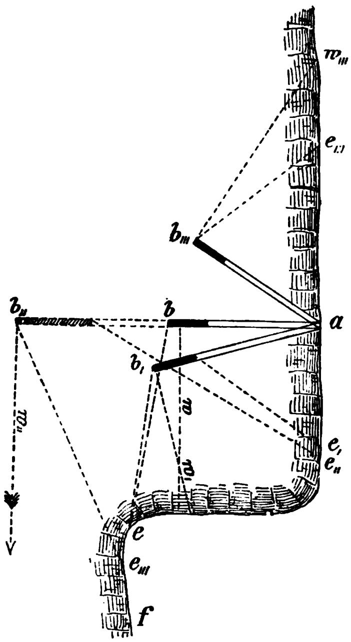


Fig. 65.

The stratification and fissuring of the rock influence the proper position of bore-holes and the effect of the explosion.

If the individual strata are thick the bore-hole can be wholly in one stratum (Fig. 66). As the surface of two strata cohere much less strongly than the mass of each one, they are nearly equivalent to a free surface;

consequently, the bore-hole should not be driven down to the division between strata, and slightly smaller charges can be used. If the strata are inclined (Fig. 67), then the charge has a little less work to do, as the rock at the moment of breaking away tends to fall by its own weight. If the strata are thin, the bore-hole must be driven parallel to them so that it is entirely in one stratum (Fig. 68).

A bore-hole should not be driven between two strata,

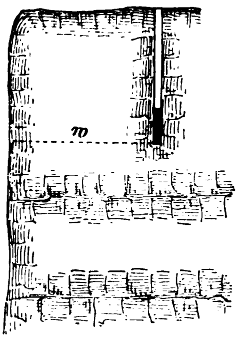


FIG. 66.

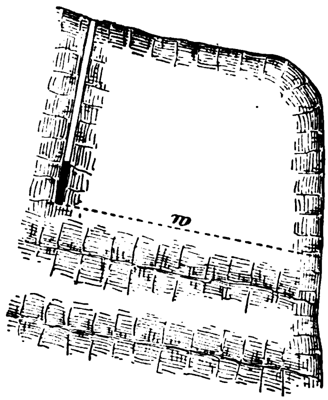


FIG. 67.

nor should it cross several at right angles, as a more or less violent shaking of the rock would be the only result, because the gases produced by the explosion would leak away along the junctions of the strata, before they would exert their full effect. If the rock is much jointed or slaty, blasting can only be used to lessen the manual labour, as it is only by comparatively powerful charges that it can then be broken down. In the case where, when work is commenced, there is no second free face (from undercutting, etc.), the operations are started by breaking-in shots 1, 1, 1 (Figs. 69 and

70), the number of which depends upon the size of the end and the hardness of the rock. The bore-holes for these are drilled so as to converge inwards, the mouths being as far apart as possible so as to get a large free surface; they are also made as deep as possible so that the enlarging shots, 2, 2, 2 and 3, 3, 3, 3, may have a large free surface to work upon. As a rule the bore-holes for the breaking-in shots do not meet, in order that there may be a wide end to the cavity broken out by them.

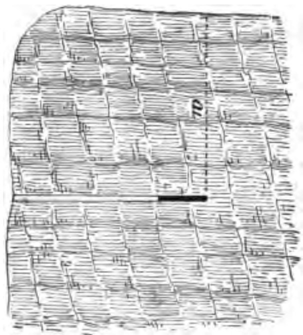


FIG. 68.

The number and position of the bore-holes for the

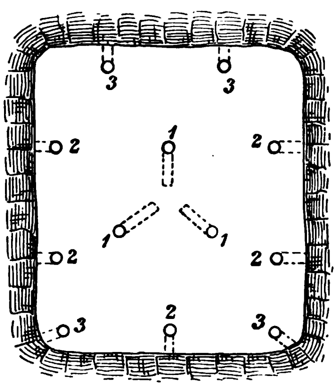


FIG. 69.

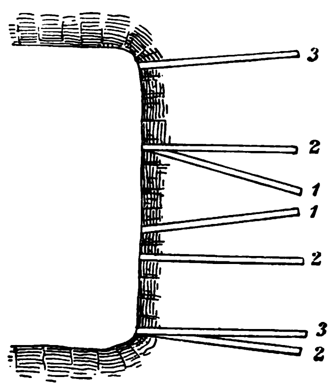


FIG. 70.

enlarging shots depends upon the contour of the working and the explosive used. As the corners of the working end are more in tension, efforts must be made to remove this as much as possible. It is best to first blast the breaking-in holes, then the middle ones, 2, 2, 2, so as to give the charges in 3, 3, 3, 3 as large a free surface as possible to work upon. At the roof the breaking down is somewhat easier, but the conditions of space make it necessary to drill the holes at a slight angle upwards; they should, however, be kept as nearly horizontal as is possible from the shape of the workings. If the outline of the working face is large, the widening shots are arranged concentrically round the breaking-in shots (Fig. 71). If the ignition is done electrically, the shots are fired in the order of the numbers. If a time-fuse is used, the charges that have to be fired first have the shortest fuses, and so on; in this way the charges fired last can be made somewhat smaller.

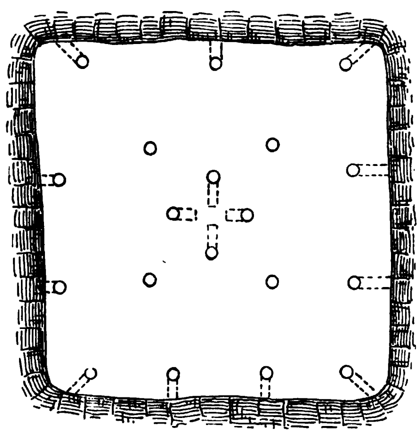


FIG. 71.

The distance between bore-hole and bore-hole may be taken as equal to the line of resistance, provided the charge has been correctly determined. With electrical firing it may be as much as one and a half times the line of resistance, as the shots assist each other when fired simultaneously.

Of course this must not be taken as a hard and fast rule, as the hardness of the rock, the extent of fissuring, etc., the specific gravity, and the force of

FIG. 72.

FIG. 73.

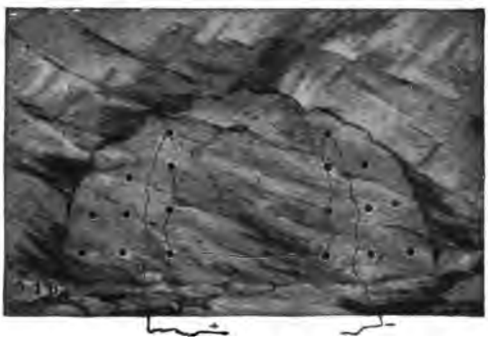


FIG. 74.

FIG. 75.

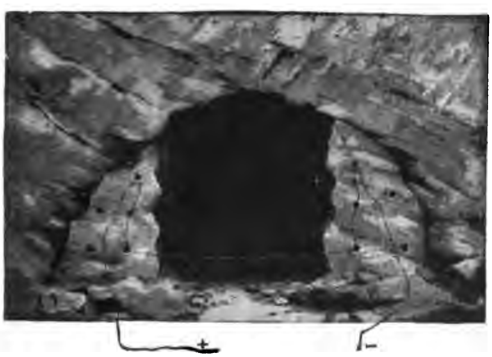


FIG. 76.

FIG. 77.

the explosive all affect the size of crater each shot will throw out.

Figs. 72 to 77 show the American method of working in a heading. A series of breaking-in shots are drilled (Fig. 74), which diverge vertically (Fig. 72), but in the horizontal plane the two centre-holes meet (Fig. 73). After firing the breaking-in shots either the curtain walls and sides are thrown down simultaneously

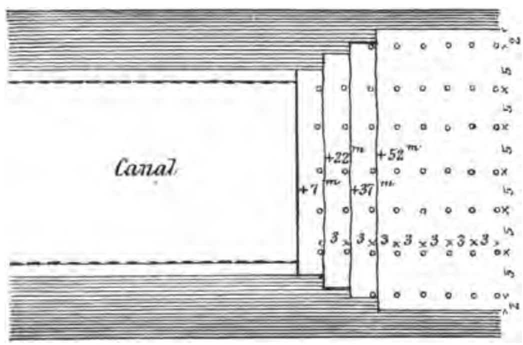


FIG. 78.

(Fig. 75), or the curtain walls are attacked first (Fig. 76) and the sides afterwards (Fig. 77).

These few typical examples will serve as guides for all cases likely to occur, if taken with what is said further on concerning the size of charge.

Deep Bore-holes.—A very ingenious method of breaking down long walls of rock was used by Münch and Gerster in the construction of the Corinth Canal. Bore-holes the whole depth of the face—60 metres, or about 197 feet—were sunk by the Topham drill (Fig. 58). They were then filled to a depth of 45 metres—$147\frac{1}{2}$ feet about—with sand, and a dynamite charge put in and tamped with sand to the top of the bore-hole. (Figs. 78 and 79.)

After this charge was fired the sand was taken out of the bore-hole for 15 metres down and a second blast made, and so on until the full depth was used. By dividing the face of the rock into four steps, each having a series of bore-holes, and firing them in series electrically, the work was got through very rapidly. The rock-drill was on rails, and drilled a hole in about 10 hours; it was then moved on to the position of the next hole, the rods being left behind to be extracted by another gang of men, and a fresh lot used for the second hole. To remove the sand from the bore-holes, iron cylinders with a spiral drill at their end and four wings on the side for conveying the sand loosened by the drill into the cylinder, were used.

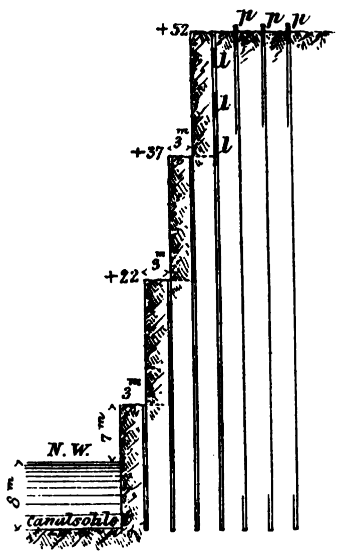


FIG. 79.

Firing by series in stepped workings has always been a favourite method of blasting, and is a convenient and effective process. In two such operations, in the open cast coal-mines of Trifail, witnessed by the author, the following figures were obtained: In the first, 1100 kgms. (21¾ cwts. about) of dynamite No. 3 and 138 kgms. (2¾ cwts. about) of dynamite No. 2 were charged into a series of bore-holes about 40 in number, which would break down, according to the average results there, about 7322 cubic metres (9578 cubic yards about). In the second blast, about 562 kgms. (or about 11 cwts.) of dynamite No. 3 were used, which would break down 2763 cubic metres, or about 3614 cubic yards.

CHAPTER VI.

CHAMBER MINES.

a. **Chambers produced by Blasting.**—In order to be able to use a larger and more concentrated charge, bore-holes are chambered, or enlarged, at their far end. This may be effected by exploding at the bottom of a deep bore-hole a strongly tamped charge of dynamite,

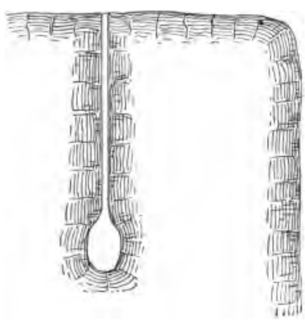


FIG. 80.

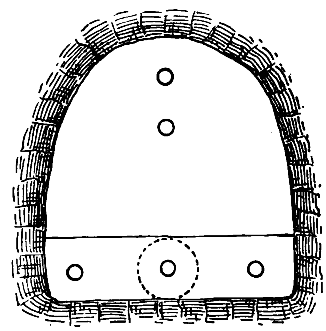


FIG. 81.

the quantity used being too small to break down the rock; it has the effect of shattering the rock locally, and produces a chamber (Fig. 80), which may sometimes be enlarged by repeating the process. At the mines of Blanzy, France, a deep hollow is made in a similar manner (Figs. 81 and 82). On the floor of the heading a bore-hole 3 metres (10 feet) deep and 0.040 metre diameter ($1\frac{1}{2}$ inches) is driven, and then

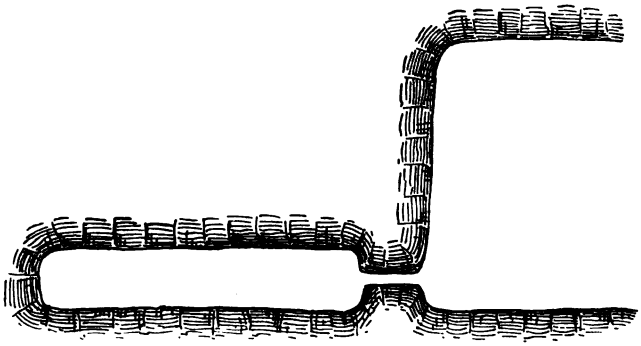


FIG. 82.

chambered out by exploding two or three successive charges of blasting gelatine in it; the two lower bore-holes are then fired electrically, breaking down the side

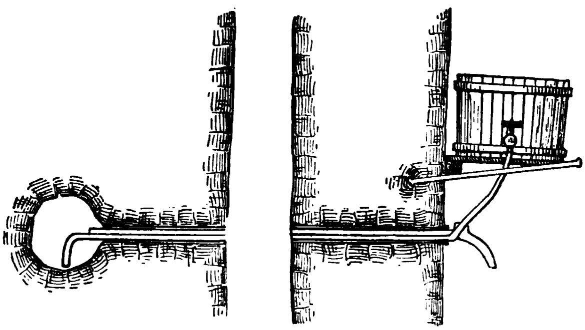


FIG. 83.

walls of the chamber, and producing a deep hollow as wide as the working.

b. **Chambers produced by Corrosion.**—Bore-holes in rocks that are easily attacked by acids, such as limestone, dolomite, etc., may sometimes be chambered with advantage by corrosion (as first suggested by Courberaise in 1844).

This is done by inserting into the bore-hole a copper tube bent down at one end (Fig. 83). Above this is placed a tub with a wooden tap, containing hydrochloric acid, a quantity of which is allowed to run in down a rubber tube, which enters the copper pipe by a faucet at the top of the bend, and passes along it to the bottom of the bore-hole. When the action of the acid is over, a fresh supply is run in; this forces out the spent acid along the copper tube, which can be used a second time.

The following figures were obtained from mine-chambers made in this manner during the construction of the harbour at Fiume: 1 litre (1.8 pints) of hydrochloric acid produced 0.053 cubic metre (1.87 cubic feet) of chamber space in 48 minutes; this is about 19 litres to the cubic metre, or about 3½ gallons per cubic yard.

The circumstances under which chamber-mines can be used with advantage are of rare occurrence; the bore-holes must not be too deep. Their usual object is to break down rock on one free face with bore-holes that have been drilled from another. It will be clear from what has already been said, that such a concentrated charge can only act through a limited distance if the consumption of the explosive is to be kept within reasonable limits. The limiting factor in making chambers is the cost, which increases at an enormous rate with the size of the chamber. It is therefore evident that if chamber-mines are to be economical, the bore-holes must not be deeper than from 16 to 20 feet. In most cases, when proper drilling arrangements are available, a number of bore-holes fired electrically will be more suitable.

c. **Large Blasts (Giant Mines).**—The use of very large charges is in many cases very advantageous in quarries, where there is a ready sale for building material and road-metal, and also where very large blocks are required, such as are used for harbour works, etc. These large charges of gunpowder, or of dynamite containing a low

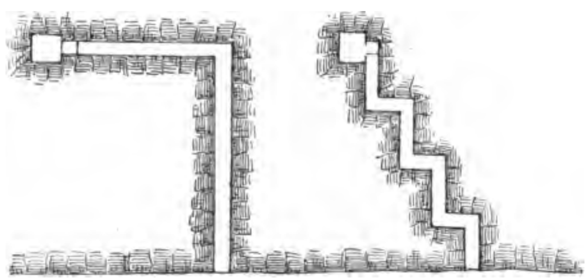


Fig. 84.

percentage of nitro-glycerine, which are known as giant mines, are laid in chambers well inside the rock; but though they break down enormous quantities of stuff, they have only a small shattering effect. With gunpowder the total effect is rather less than with dynamite, and the cost consequently rather higher; but local considerations sometimes make its use preferable. The construction of such a giant mine is as follows. A level (or sometimes a shaft) is first driven into the rock; it has either a single right angle turn in it, or a zigzag direction (Fig. 84), the centre lines of the forward parallel parts being at least 3 feet apart. A suitable size for the level is 2 feet 8 inches in width and 4 feet high, which permits easy communication. When the level has been driven in a sufficient distance a small winze is sunk for about 10 feet; from this the mine-chamber is branched off at right angles (Fig. 85). The level is made in this tortuous shape to prevent the gases produced by the explosion blowing straight out.

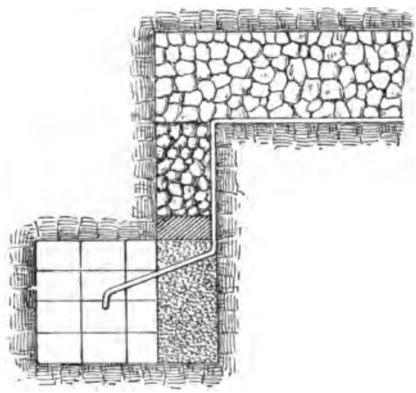


Fig. 85.

Powder is placed in the chamber, either in bags or barrels; dynamite No. 3 (containing about 15 per cent. nitro-glycerine, 10 per cent. charcoal, and 75 per cent. saltpetre), in open boxes or linen bags coated with paraffin wax, which are packed together as tightly as possible. In the centre is placed the firing-charge, consisting of

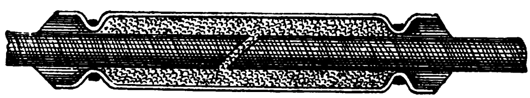


Fig. 86.

a number of gun-cotton or blasting gelatine cartridges, two of which have detonators and fuses inserted, and two are provided with electric detonators. The fuses and conducting wires pass out along the side of the level inside a wooden casing, or a lead tube, $1\frac{1}{2}$ inches in diameter.

The conducting wires should be tested with an electric firing machine before they are placed in the level, and all connections very carefully made. The lengths of fuse are spliced by paring off the ends diagonally (Fig. 86). Over one end a piece of $\frac{3}{8}$-inch india-rubber tube is slipped and fastened by binding with string; some good sporting powder is then poured in, or if this is not to be had, dynamite. The end of the next piece of fuse is then inserted and secured, and finally both ends of the joint smeared with tallow. Any empty spaces in the chamber are filled with moderately moist sand.

If water comes into the chamber, a few joists are laid on the floor and planked over, and the walls lined with planking, the space between the rock and the lining being filled with sawdust or some similar material. The part of the shaft next to the charge is filled in with sand; over this about a foot of quick-setting cement mortar is laid, and the rest of the shaft, up to the level, is filled with masonry set in cement. The gallery, if filled in with dry rubble work, is sometimes provided with wooden cross-stays about every 20 feet.

Of course, safety-lamps have to be used whilst the charging and tamping is being done. The electric firing arrangement should be tried several times, in case of a failure, before the fuse is used, which is the last resource.

CHAPTER VII.

CHARGING OF BORE-HOLES.

IT is essential that the bore-holes should be made quite dry whatever explosive is used. This is evident (apart from the spoiling of part of the explosive) from the fact that the gases produced will be cooled by the presence of moisture, and some of their energy will be used in evaporating it. Although water has no effect on some explosives—blasting gelatine, for instance—the bore-holes should nevertheless be carefully dried, if possible. For the same reason, though water forms a very convenient tamping, its use is not to be recommended. In case much water finds its way into a bore-hole, or when blasting operations are carried out under water, it is often preferable to sacrifice some of the possible effect of the explosive to avoid costly draining.

Blasting-powder and similar explosives ought never to be poured loose into a bore-hole; in some countries this practice is forbidden by law, and justly so. The danger of handling loose powder near naked lamps or candles, which often throw off sparks, the possibility of its being strewn about, and the difficulty generally experienced in filling it into the bore-hole, point to the advisability of refraining from the practice altogether. It is always possible to make the powder up into cartridges with paper wrappers before taking them into the mine; and in this form bore-holes at any inclination are much more easily charged. For wet bore-holes these cartridges should have two wrappers, and be dipped into a waterproofing mixture. Combes gives — 8 parts pitch, 1 part beeswax, and 1 part tallow; and Hess—6 parts beeswax, 1 part asphalt, and 1 part resin, as suitable mixtures. Another is a mixture of paraffin wax, resin, and linseed oil, the proportions varying with the melting-points of the paraffin and resin. The fuse should be placed in position and firmly tied before dipping. In Great Britain and in some other countries the manufacture of such cartridges in unlicensed places and by unauthorised persons is illegal. Compressed blasting-powder has to be treated in the same way.

If a shot firer is in charge of the work he may proceed in the following manner. Soft paraffin wax is melted in a suitable vessel, and allowed to cool down in a room away from the fire until it just begins to solidify. At this moment the cartridges are dipped into the paraffin and immediately withdrawn; after this, those that have already been dipped once are again immersed. If done in this way, the paraffin does not penetrate into the powder and the coating has no cracks. Cartridges treated thus, if they are put into the bore-hole carefully so as not to damage the coating, will remain in water for many days without deteriorating.

The tamping of the gunpowder into the bore-hole should be done as tightly as possible. Tamping bars of hard wood (ash, acacia, etc.), with a brass ferrule at the top, are the proper ones to use; they are durable, can be easily obtained, and are quite safe. The use of metal bars should be unconditionally condemned, as, even if made of copper, they may cause ignition, either through striking sparks or by a blow due to careless handling.

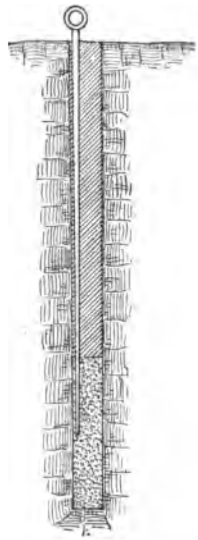


FIG. 87.

Charging with a pricker is adopted in very few mines, and should always be avoided if possible, as it is dangerous and requires delicate manipulation. If no other way of firing is available, prickers of copper or brass should be used. The pricker is placed along the side of the bore-hole (Fig. 87), the powder placed in position and pressed down, the hole tamped and the pricker carefully withdrawn. It leaves a channel down one side, into which the firing arrangement is inserted. If, as is usual, a safety-fuse is used, a knot should be made in it at the end, which is notched through at several places and brought home against the powder. The fuse must rest on the side of the bore-hole and be pulled tight. Injury to it in charging and tamping has to be avoided. The fuse should end at about half the depth of powder in the bore-hole, so as to ignite it at the middle, in which case it will burn away right and left. This is an advantage with gunpowder, which burns comparatively slowly. If the charge is ignited at the bottom, the rock will probably begin to fall before the charge has finished burning, and some of it will be thrown out, either unburnt or still burning, in which case the products of combustion will foul the air considerably more than if complete combustion had taken place. Again, if ignition is started at the top of the charge the rock may begin to fall before the combustion is completed, and, consequently, the lower part of the charge will burn away in the bottom of the bore-hole without blasting it.

A uniform and tight tamping is essential. For tamping gunpowder charges the material used should be free from quartz or other hard matter that might produce sparks or damage the fuse; hence stone-dust, coal-dust, etc. are not suitable. The best material is dry clay, which should be rammed home in layers with a wooden tamping-bar, a paper wad being placed between the powder charge and the first layer of clay; with ascending bore-holes the clay is wrapped in pieces of paper. It is a good practice to have clay rolls of the required size for tamping prepared above ground, and to have them air-dried. They may be made by children or by similar cheap labour. Their small cost is amply repaid by the saving of time to the miners, and the increased efficiency of the charge.

Dynamite and similar explosives are sold in cartridges, and, therefore, require no treatment before use. The required number are placed one by one into the bore-hole and pressed home firmly with the wooden rammer, so that the wrapping breaks and the dynamite is forced into close contact with the sides of the bore-hole. On the top of these is placed the primer with its detonator and fuse inserted. Although dynamite may be exploded directly by the use of a detonator inserted in it, it is much better, especially with the weaker dynamites, to use primers, as a powerful initial impulse is of great advantage, and is best obtained by the use of a primer; they are, as a rule, specially prepared for the purpose.

The primer is prepared or adjusted as follows. The

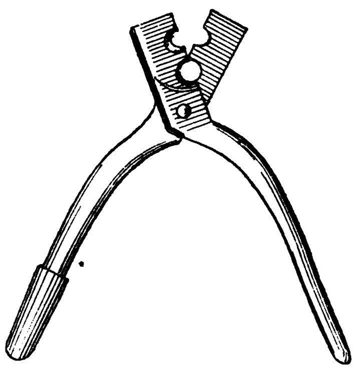


FIG. 88.

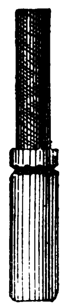


FIG. 89.

fuse is cut off clean to the required length with the cutting grooves on the detonator pliers (Fig. 88) and inserted into the detonator, which must be first freed from the sawdust, in which they are packed, by gentle tapping. The upper part of the detonator is then pinched tightly round the fuse with the other grooves in the pliers. Pinching on the detonator with the teeth, as is sometimes done, should never be attempted, as it has led to many an accident. The wrapping of the primer is then opened at one end, and a hole made in the dynamite with a small stick, or with the ebonite plug on one leg of the plier handles, if it is fitted with one; into this hole the detonator is inserted, but only so far that the fuse does not touch the dynamite; if the fuse is allowed to touch the dynamite the latter would be ignited by it prematurely, and, burning away, would produce foul gases in the workings. The opened end of the primer wrapping is tied tightly round the fuse with twine. The primer and its fuse are then carefully inserted into the bore-hole and gently pushed home into contact with the charge by aid of the rammer. A paper wad is then placed on the top and the hole well tamped, pressing lightly at first in order not to disturb or damage the fuse and detonator, a wooden rammer being used.

If a good depth of hole is left for tamping, it may be done by simply pouring in fine, dry sand, though a clay tamping is always preferable. In wet bore-holes, or in blasting under water, when the charge is to be fired immediately, the waterproof wrapping of the cartridges is sufficient to protect the charge; but in these cases the cartridges must not be burst open, but simply inserted end on in contact with one another. If the charge has to remain in a wet position for any considerable time before firing, the cartridges should be waterproofed before they are put into position. This may be done by dipping them in one of the compositions given for gunpowder cartridges (see page 110), or by placing them in a tin case (Fig. 5), the cover of which has a socket for the reception of the detonator, and which is made quite watertight. Primers for wet bore-holes should always be waterproofed by dipping as before described, or at least smeared over with tallow, pitch, or even clay, to prevent moisture getting into the detonator.

Special care must be taken that the dynamite is not frozen; it should be quite soft when charged. The cartridges should not only feel quite soft, but should be quite plastic throughout.

If electrical firing is used the tamping must be free from metal, so that the insulation of the wires may not be affected. Should a shot miss fire, it is best to leave it alone and prepare another one, as the picking out of a charged hole is always a dangerous operation. If, however, this be unavoidable, the tamping should be carefully extracted with a scraper, water being poured in continuously whilst it is being done. With gunpowder, if "a straw" has been used, another one can be inserted, but otherwise it is best to drown the charge. With dynamite the tamping can be cleared out, as above described, until the paper wad is reached, a new primer, with its detonator and fuse, inserted, the hole re-tamped, and the whole charge exploded.

CHAPTER VIII.

DETERMINATION OF THE CHARGE.

At the outset it must be stated that exact calculations for the charge to be used are very difficult to make in most cases of blasting, because the accompanying conditions may vary with each successive blast. This is especially true for quarries and railway works, but it is also true for mines in which the size of the workings and the nature of the rock vary from point to point.

It will be readily seen that the quantity of explosive required depends largely on the state of the rock to be blasted. It is different when a rock wall or an undercut coal face has to be thrown down, or when a projecting mass of rock, which often has four free sides, has to be blasted off. Again, especially in metalliferous mines, in the stopes, at an end, there may be two or more free sides, but the rock so tightly held on the top and bottom that even comparatively strong charges have little effect. Secondary advantages are also of influence, such as, for instance, when, with a wide breast of coal, one of two shots is fired first so that the other will require a smaller charge, and so forth. It will be evident on a little reflection that a bore-hole in a mass of rock held on all sides, will require an entirely different charge to one in rock held to the main body on four, three, or even a less number of sides, the minimum being reached when the piece to be blasted is a so-called free stone—*i.e.* when it is entirely unconnected.

It is, therefore, a useless expenditure of work to attempt the calculation of charges, if the nature of the rock and the relative condition of the pieces to be blasted vary from place to place. The conditions of economy in mining, and in blasting operations generally, make it necessary to leave the determination of the required charges to the workman himself, since it will seldom pay to employ an engineer solely upon this work. If, as is usual in mines, the miner has to pay for the explosive he uses, it is only fair that he should have freedom in the way it is to be used; but it is nevertheless the duty of the mine manager to give instructions in cases of imprudent working. The intelligent miner examines the rock attentively, carefully considering for each blast the position of any joints or fissures in the rock, the proper direction to be given to the bore-hole, the "loud places," and the free sides available; but it only too often happens that two miners will have different opinions as to the proper charge for a certain shot. From this frequently follows a waste of explosive, which in quarries and on railway work assumes very considerable proportions.

Most of the work being done by contract, the workmen prefer to use large charges to minimise the drilling required and the amount of lifting with bars. In quarrying building stones they are apt to use insufficient charges, for fear of breaking up the stone too much, which results in much time being wasted in wedging down the blocks.

The author would, therefore, again advise that the calculation of charges under ordinary conditions be neglected, and recommend watching attentively actual operations for some weeks, asking for explanations from the more expert miners, and if one has the other requisite knowledge—as is assumed—an amount of experience will be gained in a short time that will enable one to estimate with some precision the proper charge to use, by simply inspecting the spot to be blasted. Those cases where it is practicable to calculate the charge are considered further on; they are headings, tunnels and shafts, in which the nature of the rock and the section remain fairly constant; also such quarries, railway cuttings and open cast workings (especially of coal), as will permit of a systematically planned method of working being carried out; and, finally, giant mines, that is, the blasting of very large masses of rock with large charges.

There has been no lack of theories for the determination of blasting charges, but as their application always depends upon empirical facts obtained in practical working, only those parts will be given here that are absolutely necessary to understanding the theory of blasting.

General Rule for Charging.—For the present, the form of the charge will be neglected, and it will be assumed that it is concentrated at a mathematical point, and also that the explosive is instantaneously converted into gas at the moment of firing so as to exert a large pressure distributed uniformly over all parts of the rock surrounding it. If the charge is strong enough to overcome the resistance presented by the cohesion of the rock, the latter will be broken into pieces. If the charge is too feeble to effect this, the pressure set up will be consumed partly in enlarging the cavity occupied by the charge and partly in condensing the gases liberated by the explosion to a liquid state, or in giving rise to the formation of solid compounds. If the charge is imagined to be at the centre of an unlimited, easily compressible mass, the gases, having no means of escape and exerting an equal pressure on all the surrounding parts of the mass, will enlarge the space originally occupied by the explosive into a spherical cavity. Hence it follows that the quantity of a charge, which is concentrated at a mathematical point, has a direct ratio to the sphere affected by its explosion. Calling the coefficient of an explosive c, and the charge L, we have (since the solid contents of a sphere $= 4.1888r^3$ where $r =$ radius of the sphere) $L = 4.1888r^3c$.

This general rule cannot be applied in practice, as the conditions assumed never obtain in actual work. One never has unlimited masses to deal with, but, on the contrary, a certain definite resistance has to be overcome.

Blasting out of the Solid (*i.e.* one free side) with a Concentrated Charge. — Imagine a concentrated charge to be placed at L (Fig. 90) (its best form would be spherical), and surrounded by solid rock for a long distance on every side but one—namely, towards the surface, *A B*. The pressure generated by the explosion encounters resistance that is practically infinite in all directions, except towards the surface, *A B*. Assume that the measure of the force of the charge, that is, the radius of its sphere of effect, is equal to the perpendicular distance, *L M*, of *L* from the surface *A B*.

The effect of the explosion will, therefore, only just

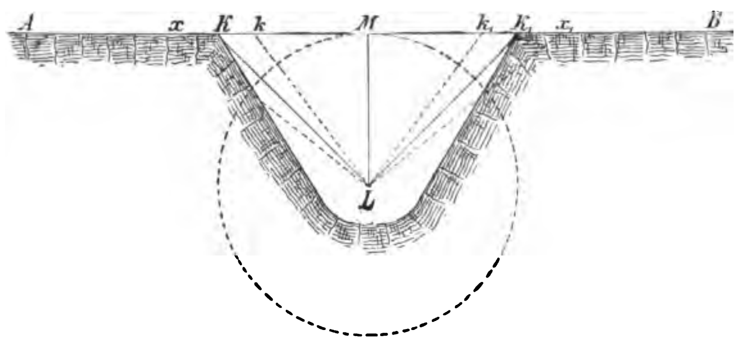


FIG. 90.

touch the surface at the point *M*. But as a larger or smaller amount of the force developed, depending on the compressibility and elasticity of the rock, is reflected back from the sides where the great resistances are, towards the free surface, a larger or smaller area will be affected instead of the point *M* only. This area will have its boundary at the line where the total available effect just ceases to reach the surface. The result of the explosion will be the projection of a cone, such as $K\ L\ K_1$. For a weaker charge it of course follows that the solid angle of the cone will be less, say $k\ L\ k_1$; if it is stronger, the angle will be larger, $x\ L\ x_1$, for instance. If the charge be strong enough to have some effect in the other directions the crater will be altered in form by the crushing and fissuring of the rock, and will be widened below *L*, and will in reality assume a form similar to that shown in full lines (Fig. 90). It is clear that the radius of the mouth of the crater (*i.e.* *K M*, which will be referred to in future as *r*) and, also, the solid contents of the crater, depend only upon the quantity of the charge, provided the explosive used and the material operated on remain the same. It will be seen that the force increases disproportionally to the size of crater, and that a disproportionate amount of force is lost if the radius, *r*, became greater than the least distance, *L M* (in future called *w*), to the surface (*i.e.* the line of resistance); and *vice versâ* if the increase of the line of resistance *w* is not proportional to the increase of *r*.

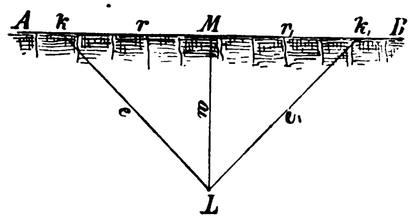


FIG. 91.

In Fig. 91, let *L M* be the line of resistance, *w*, from a mine, L, and the crater radii, r, r_1; then the lines $k\ L$ and $k_1\ L$ are called the radii of explosion, e, e_1. If the line of resistance remains the same while the charge is increased, the crater becomes larger and, consequently, the radius of explosion, *e*, longer; thus *e* can be considered as the measure of the force which has affected the surface and is the radius of the sphere of action of the charge. Consequently, the effect of an explosion can be taken as proportional to the third power of the radius of explosion, *e*.

Experience has shown that, as a rule, this is perfectly correct; but though it is true, the many secondary effects which have to be considered alter the hypothetical results, and no absolute values can be deduced from the rule for charging based on it. If *c* is the coefficient of effect of an explosive, then, according to the above, $L = ce^3$, or $c = \frac{L}{e^3}$; since $e = \sqrt{w^2 + r^2}$, the formula becomes, in terms of *w* and *r*, $L = c\ (\sqrt{w^2 + r^2})^3$ where *L* must be expressed in pounds and *w* and *r* in feet.

With this the theory is at an end, and its further application depends largely upon experience gained in actual work.

This theory indicates that a line of resistance, *w*, should be of the same length as the crater radius; but the results of a large number of blasts show that, in consequence of the reflected action mentioned above, the limit for a regular action is reached when $\frac{r}{w} = n = 1.50$ or $\frac{e}{w} = p = 1.80$—that is:

line of resistance	:	crater radius	: :	2 : 3;	or
line of resistance	:	radius of explosion	: :	5 : 9.	

If the formula $L = c\ (\sqrt{w^2 + r^2})^3$ be within the limits $n \leqq 1.50$ and $p \leqq 1.80$, we have as an approximate formula:

$L = 0.36c\ (w + r)^3$, or, writing *k* for the constant 0.36 *c*,

$$L = k\ (w + r)^3 \text{ and } k = \frac{L}{(w + r)^3}.$$

The following table is calculated on this basis :—

Table for Concentrated Charges with One Free Side.

$L = k\ (w + r)^3$. Right proportion $\frac{r}{w} > 0.75 < 1.50$.

The coefficient $k = 0.010$; if $k <$ or $>$ 0.010, then L is to be multiplied or divided accordingly.

$w+r$ = feet.	L = lbs.	$w+r$ = feet.	L = lbs.	$w+r$ = feet.	L = lbs.	$w+r$ = feet.	L = lbs.
9	7.29	22	106.48	35	428.75	48	1105.92
10	10.00	23	121.67	36	466.56	49	1176.49
11	13.31	24	138.24	37	506.53	50	1250.00
12	17.28	25	156.25	38	548.72	51	1326.51
13	21.97	26	175.76	39	593.19	52	1406.08
14	27.44	27	196.83	40	640.00	53	1488.77
15	33.75	28	219.52	41	689.21	54	1574.64
16	40.96	29	243.89	42	740.88	55	1663.75
17	49.13	30	270.00	43	795.07	56	1756.16
18	58.32	31	297.91	44	851.84	57	1851.93
19	68.59	32	327.68	45	911.25	58	1951.12
20	80.00	33	359.37	46	973.36	59	2053.79
21	92.61	34	393.04	47	1038.23	60	2160.00

If n and p, the indices of a mine, are larger than 1.50 and 1.80 respectively, the charge required, as mentioned above, increases disproportionately to the work done, and for each particular case a coefficient, q, has to be added to the formula, making the equation :

$$L = q\ k\ (w + r)^3 \text{ and } k = \frac{L}{q\ (w + r)^3}.$$

The following table has been calculated from values of q obtained experimentally :—[1]

Index p =	0.00 to 1.80	1.85	1.90	1.95	2.00	2.05	2.10
,, n =	0.00 ,, 1.50	1.56	1.62	1.67	1.73	1.79	1.85
Coefficient q =	1.00	1.08	1.17	1.28	1.40	1.53	1.68

Index p =	2.15	2.20	2.25	2.30	2.35	2.40	2.45	2.50
,, n =	1.90	1.96	2.01	2.07	2.13	2.18	2.24	2.29
Coefficient q =	1.83	2.00	2.17	2.36	2.55	2.74	2.95	3.16

Index p =	2.55	2.60	2.65	2.70	2.75	2.80
,, n =	2.35	2.40	2.45	2.51	2.56	2.62
Coefficient q =	3.37	3.59	3.81	4.03	4.25	4.48

It is clearly evident from the above that it is very disadvantageous to make p larger than 1.80, or n larger than 1.50; or, in other words, to employ too powerful a charge.

If the quantity of charge L and the coefficient of effect k be known, the crater-radius, r, and therefrom the sphere of effect of the mine, can be determined by solving the formulæ :

$$e^1 = \sqrt[3]{\frac{L}{k}} \times 0.36 \times 2\,;$$

$$= \sqrt[3]{\frac{L}{k}} \times 0.72\,; \text{ and}$$

$$r = \sqrt{(e^1)^2 - w^2}.$$

If p^1 is larger than 1.80, that is, if $\frac{e^1}{w} > 1.80$, then the value of e^1 obtained has to be multiplied by a coefficient, which may be found from the following table :—

[1] Part 17 of the "Imp. Roy. Engineer Corps Technical Instructions."

$\frac{e^1}{w} = p_1 = 0.00$ to	1.8	1.9	2.0	2.1	2.2	2.3	2.4
value f for $e =$	1.00	0.97	0.95	0.92	0.90	0.88	0.86
$\frac{e^1}{w} = p_1 = 2.5$	2.6	2.7	2.8	2.9	3.0	3.1	3.2
value f for $e = 0.84$	0.82	0.80	0.78	0.77	0.76	0.74	0.73
$\frac{e^1}{w} = p_1 = 3.3$	3.4	3.5	3.6	3.7	3.8	3.9	4.0
value f for $e = 0.72$	0.71	0.71	0.69	0.68	0.67	0.66	0.65
$\frac{e^1}{w} = p_1 = 4.1$	4.2	4.3	4.4	4.5	4.6	4.7	
value f for $e = 0.64$	0.64	0.63	0.62	0.62	0.61	0.61	

Examples: Given $k = 0.010$, $w = 15$ feet, $r = 15$ feet; then is

$$p = \frac{\sqrt{w^2 + r^2}}{w} = 1.41\ ;\ n = \frac{r}{w} = \frac{15}{15} = 1\ ;\ L = k\,(w + r)^3 = 270 \text{ lbs.};$$

and, therefore,

$$k = \frac{270}{(15 + 15)^3} = 0.010;\ e^1 = \sqrt[3]{\frac{L}{k}} \times 0.72 = 21.6 \text{ feet};\ p_1 = \frac{21.6}{15} = 1.44 \text{ feet}$$

thus < 1.80, and therefore is $r = \sqrt{(e^1)^2 - w^2} = 15.54$ feet instead of 15 feet.

Given $k = 0.015$, $w = 9$ feet, $r = 21$ feet;
then

$$p = \frac{\sqrt{81 + 441}}{9} = 2.54\ ;\ n = \frac{21}{9} = 2.33\ ;$$

therefore

$$L = q\,k\,(w + r)^3 = 3.37 \times 0.015 \times (9 + 21)^3 = 1364.85 \text{ lbs.};$$

and consequently

$$k = \frac{L}{q\,(w + r)^3} = 0.015\ ;\ e_1 = \sqrt[3]{\frac{1364.85}{0.015}} \times 0.72 = 32.38 \text{ feet.}$$

$p_1 = \frac{32.38}{9} = 3.60$ feet; thus it is > 1.80; therefore e must $= e_1 \times f$ $= 32.38 \times 0.69 = 22.34$ feet, instead of 22.85 feet; and $r = \sqrt{e^2 - w^2} = \sqrt{418} = 20.45$ feet instead of 21 feet.

Blasting with Concentrated Charges, when there are Two or More Free Sides.—Suppose a charge, L, is capable of throwing out a crater, *a L K* (Fig. 92), towards the free side, $K_{\prime\prime\prime}\ K\ K_{\prime}$, and also that the mass to be blasted has another free side, $K\ K_{\prime\prime}$, the charge will have to break out a crater towards both sides, and each crater will be smaller than if only one free side existed. If $w = w_{\prime}$ and L is no larger than is just

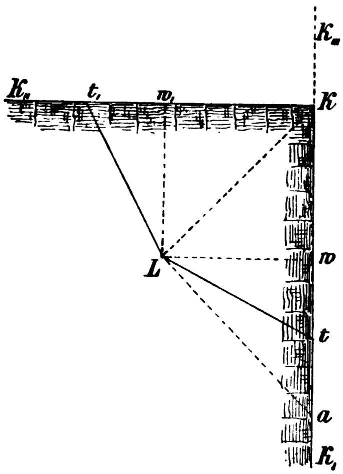


FIG. 92.

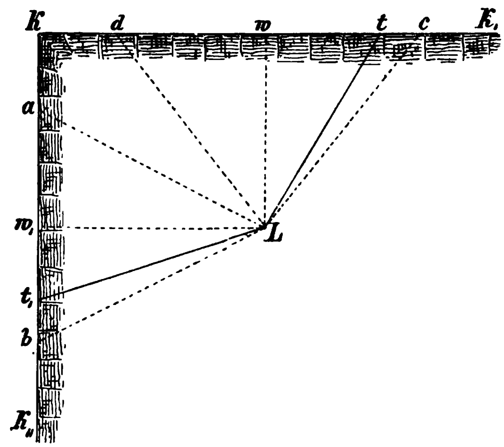


FIG. 93.

necessary, then the bounding surfaces of the two craters will touch each other, and the rock between them being affected by the partially reflected force, a crater with an outline, $t\,L\,t_{\prime}$, will be formed. But if $w < w_{\prime}$, then the two craters, *c L d* and *a L b* (Fig. 93), corresponding to the charge, *L*, would not touch (providing the material between them was connected near to *K* with the solid rock). This not being the case, part of the force, acting jointly with the part reflected, will be absorbed in throwing down the mass, $K\ d\ L\ a$, and less will be available in the directions $K_{,}$ and $K_{,,}$; the crater will take the form $t\ L\ t_{,}$. As the force is directed more along $w_{,}$, the shorter of the two lines of resistance, it follows from what has been stated, that the volume of the material broken down by equal charges is greater when there are two free sides instead of one, or *vice versâ*, that the same effect may be obtained with a smaller charge.

Applying the figures that have been shown to hold good for blasting when there is only one free side, it will be seen that the ratio of the distances between the charge and the two free sides must not be greater than 2 : 3, if the maximum result from the required charge is to be got; this has been confirmed by experiment.

It will be readily understood that, as the number of free sides increases, the firmness with which the part to be blasted is held decreases, and, consequently, smaller charges can do the same work, or, with the same quantity of explosive, a larger amount of stuff can be broken down. The general rule is always applicable that the ratio of the shortest to the longest line of resistance must not exceed 2 : 3 if the maximum effect is to be obtained. It is best to place the charge so that the shortest line of resistance is horizontal and the longest vertical, as then the weight of the rock assists the breaking down.

It is scarcely possible to give an exact rule for the quantity of each charge for blasting when there are several free faces. But it may be assumed that the proper charge for one free face—calculated from the table on page 123—divided by the number of free faces, gives approximately the proper charge to use. So that the charge required to blast from a single free face can be reduced

To one-half	for two	free faces.		
,,	third	,, three	,,	,,
,,	fourth	,, four	,,	,,
,,	fifth	,, five	,,	,,
,,	sixth	,, six	,,	,,

the last case being that of an unattached block or a so-called "free stone."

It is a good plan to determine the coefficient *k* by making a small blast out of the full, and then others with two or three free sides, to determine how far the above proportions require altering.

Blasting Tightly-bound Material.—When the rock or other material is firmly connected on at least *two opposite* sides to the main mass, it is said to be *tightly bound*, and the blasting of such a piece requires very different charges to those considered above, a proportionately larger charge being required than would otherwise be necessary with the number of free faces present.

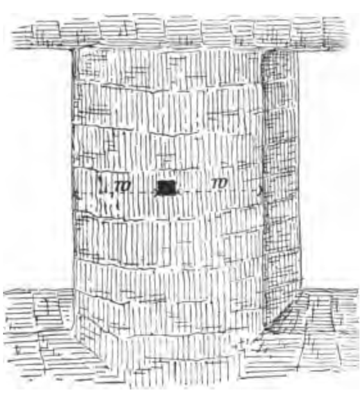


FIG. 94.

The simplest case is that of a pillar (Fig. 94). If the size is great enough, and an effect on one face only is wanted, the case is the same as blasting out of the full—*i.e.* with one free surface. If it is required to break away the whole of the middle part, experience has shown that the charge must be increased by one-half, in which case it is best to put the charge on the axis of the pillar, as when the two lines of resistance are unequal, since the effect of the charge along them decreases as the third power, the effects towards each face will be still more unequal, and a proportionately larger charge would be necessary to get the same result in both directions. If the part to be blasted is tightly bound on several sides—including, of course, two opposite ones—the quantity of charge increases with the number of bound sides.

Blasting in Varying Strata.—With a big blast it frequently happens that the part it is required to throw down consists of several strata which vary in hardness. It is then essential that the charge be placed, if possible, entirely in the thickest stratum; for if the mine-chamber crosses the junction of two or more strata, a larger charge will have to be used.

CHAPTER IX.

BLASTING IN BORE-HOLES.

Blasting with Extended Charges. — In the most common class of blasting operations the charge is placed in bore-holes, in the form of a cylinder, having a length several times greater than its diameter. Such a charge is called an *extended charge*, and can be considered as an uninterrupted series of concentrated charges. Imagine, as was done in the case of a concentrated charge, an extended charge to be exploded in the centre of an indefinitely large, easily compressible mass (Fig. 95), and consider it for the time being to be made up of a series of independent concentrated charges. Each of these will have its sphere of action, and as these spheres intersect and reinforce one another, the cavity produced by the combined action will be ellipsoidal, the mutual reinforcement being greatest at the centre of the charge. If such a charge be exploded in a mass having a free surface, then, as in the case of a concentrated charge, a crater will be formed, but its mouth will be elliptical. By increasing the length of the charge the ellipse gets longer, until finally the crater assumes the form of a deep groove. The crater also ceases to be elliptical when there is more than one free surface. Suppose, as in Fig. 96, there are two free faces, the charge has then but little effect towards the solid mass of rock, and, consequently, so much more towards the free faces, because there is less resistance in that direction, and also, because the solid mass reflects back some of the force. The crater will consequently have an irregular shape, the more so the more free sides there are.

Experience has shown that extended charges can be

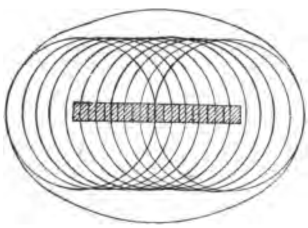


FIG. 95.

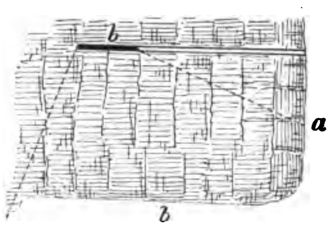


FIG. 96.

calculated directly from the line of resistance, because the weight of the charge per foot of the part to be blasted increases evenly with the square of the line of resistance, w. Keeping the same symbols as before, we have then the formula

$$L = k\,w^2 \text{ and } k = \frac{L}{w^2},$$

where k is the coefficient depending on the nature of the rock, and L the charge in ounces per foot run.

Consider, then, a fairly general case, such as driving a heading in coal (Figs. 97 and 98). A bore-hole, b, is driven so as to act towards the undercutting, p, and the breast, o. As the coal is tightly bound on all other sides it can only be broken out on the two free faces. The volume of the part thrown down is then only determined by the thickness of the seam, and consequently varies with the line of resistance, *w*. The propagation of a shock being, as is well known, inversely as the distance, the force required will vary as the square of the line of resistance—*i.e.* the square of *w*.

This general explanation will be sufficient to show the

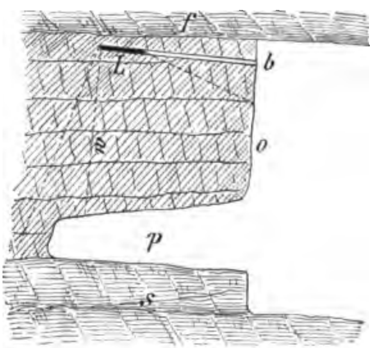


Fig. 97.

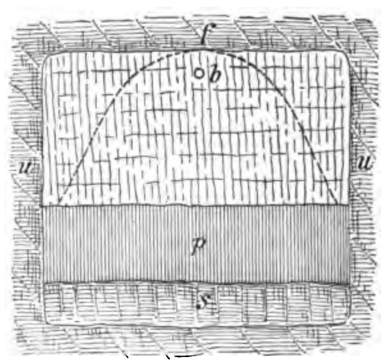


Fig. 98.

truth of the formula $L = k\,w^2$. The line of resistance, *w*, must by no means be taken to be the shortest distance from the charge to the face, as is often incorrectly done. Suppose Fig. 99 to represent a mass to be blasted with free sides along *A B C D E*, and that the charge is accurately calculated for *w* as the line of resistance. Instead of throwing out the normal crater, *a L b*, this charge, being insufficient to overcome the resistance towards *B C*, will only throw out an irregularly shaped crater, $a_{\prime}\, b_{\prime}$. In order to obtain a normal crater, $w_{\prime}$ must be taken as the line of resistance (*burden*, work to be done), and consequently as a measure of the force required.

Therefore it follows, *that the longest distance from the charge to the free face, in the direction of the desired*

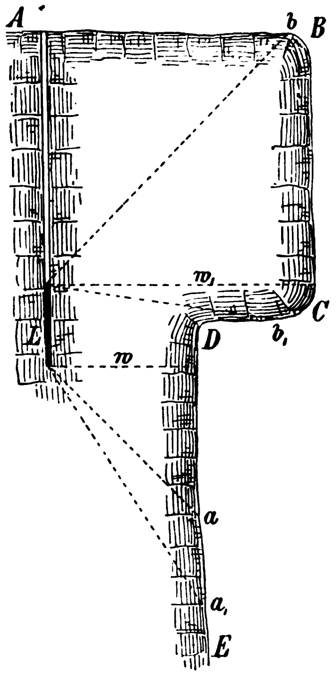


FIG. 99.

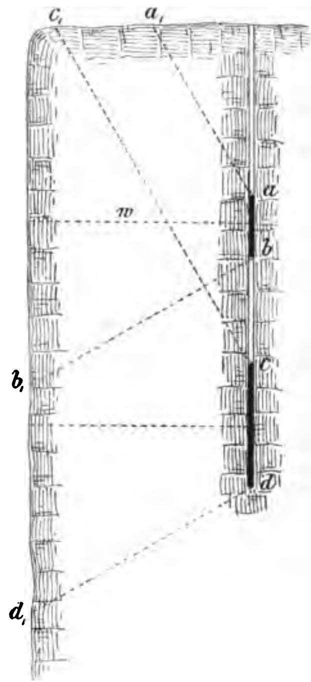


FIG. 100.

effect, has always to be taken as the line of resistance—that is, $w_{\prime}$ in Fig. 99, and not *w* or *b*.

It will be noticed that, in Fig. 99, the bore-hole is driven too far. In order not to have to waste a large charge, which would be required on account of *A B C D* offering much less resistance on the part *D E*, it would be better to first throw down *A B C D* by using a shorter bore-hole and smaller charge; and then the part *D E* by a subsequent blast.

The object of blasting operations with extended

Table of Charges for Bore-holes.

$L = k w^2$; $k = \frac{L}{w^2}$, with two free sides.

Coefficient k =	0.05	0.06	0.07	0.08	0.09	0.100	0.125	0.150	0.175	0.200	0.250	0.300	0.350	0.400	0.450	0.500
Longest line of resistance w = feet.	Charge in ounces and drams per foot-length of bore-hole.															
1¾	0^{3}	0^{3}	0^{4}	0^{4}	0^{5}	0^{5}	0^{6}	0^{7}	0^{9}	0^{10}	0^{12}	0^{15}	1^{1}	1^{4}	1^{6}	1^{9}
2	0^{3}	0^{4}	0^{5}	0^{5}	0^{6}	0^{7}	0^{8}	0^{10}	0^{11}	0^{13}	0^{15}	1^{3}	1^{6}	1^{10}	1^{13}	2
2¼	0^{4}	0^{5}	0^{6}	0^{7}	0^{7}	0^{8}	0^{10}	0^{12}	0^{14}	1	1^{4}	1^{8}	1^{12}	2	2^{4}	2^{8}
2½	0^{5}	0^{6}	0^{7}	0^{8}	0^{9}	0^{10}	0^{13}	0^{15}	1^{2}	1^{4}	1^{9}	1^{14}	2^{3}	2^{8}	2^{13}	3^{2}
2¾	0^{6}	0^{7}	0^{8}	0^{10}	0^{11}	0^{12}	0^{15}	1^{2}	1^{5}	1^{8}	1^{14}	2^{4}	2^{10}	3	3^{6}	3^{12}
3	0^{7}	0^{9}	0^{10}	0^{12}	0^{13}	0^{14}	1^{2}	1^{6}	1^{9}	1^{13}	2^{4}	2^{11}	3^{2}	3^{10}	4^{1}	4^{8}
3¼	0^{8}	0^{10}	0^{12}	0^{14}	0^{15}	1^{1}	1^{5}	1^{9}	1^{13}	2^{2}	2^{10}	3^{2}	3^{11}	4^{4}	4^{12}	5^{5}
3½	0^{10}	0^{12}	0^{14}	1	1^{2}	1^{4}	1^{9}	1^{13}	2^{2}	2^{7}	3^{1}	3^{11}	4^{4}	4^{14}	5^{8}	6^{2}
3¾	0^{11}	0^{13}	1	1^{2}	1^{4}	1^{7}	1^{12}	2^{2}	2^{7}	2^{13}	3^{8}	4^{3}	4^{14}	5^{10}	6^{5}	7^{1}
4	0^{13}	0^{15}	1^{2}	1^{5}	1^{7}	1^{10}	2	2^{6}	2^{13}	3^{3}	4	4^{13}	5^{10}	6^{6}	7^{3}	8
4¼	0^{15}	1^{1}	1^{4}	1^{7}	1^{10}	1^{13}	2^{4}	2^{11}	3^{3}	3^{10}	4^{8}	5^{6}	6^{5}	7^{4}	8^{2}	9
4½	1	1^{3}	1^{7}	1^{10}	1^{13}	2	2^{9}	3^{1}	3^{9}	4^{1}	5^{1}	6^{1}	7^{1}	8^{2}	9^{2}	10^{2}
4¾	1^{2}	1^{6}	1^{10}	1^{13}	2	2^{4}	2^{13}	3^{6}	3^{15}	4^{8}	5^{10}	6^{12}	7^{14}	9	10^{2}	11^{4}
5	1^{4}	1^{8}	1^{12}	2	2^{4}	2^{8}	3^{2}	3^{12}	4^{6}	5	6^{4}	7^{8}	8^{12}	10	11^{4}	12^{8}
5¼	1^{6}	1^{11}	1^{15}	2^{3}	2^{8}	2^{12}	3^{7}	4^{2}	4^{13}	5^{8}	6^{14}	8^{4}	9^{10}	11	12^{6}	13^{12}
5½	1^{8}	1^{13}	2^{3}	2^{7}	2^{12}	3	3^{13}	4^{9}	5^{5}	6^{1}	7^{9}	9^{1}	10^{10}	12^{2}	13^{10}	15^{2}
5¾	1^{10}	2	2^{5}	2^{11}	3	3^{5}	4^{2}	4^{15}	5^{13}	6^{10}	8^{4}	9^{14}	11^{9}	13^{4}	14^{14}	16^{9}
6	1^{13}	2^{3}	2^{8}	2^{14}	3^{4}	3^{10}	4^{8}	5^{6}	6^{5}	7^{3}	9	10^{13}	13^{13}	14^{6}	16^{3}	18

charges is, as a rule, different to that when concentrated charges are used, the difference being the way in which the rock is to be broken off. In headings, levels or shafts, the aim is to break down as much as possible without damaging the roof, walls, or floor. As in larger galleries, or in quarries, one cannot be sure of the effect beyond a certain distance, the bore-holes are so placed as to give an effect in one direction only—namely, parallel to the free face in that direction. Suppose that the charge *a b* in a bore-hole (Fig. 100) would throw out a crater $a_{,} b_{,}$; if the bore-hole is double the length, then the charge, *c d*, also would have to be greater in order to affect the whole seam.

This is why it is necessary to determine the charge per foot run; if it were calculated from the line of resistance only the charge would be the same in both cases, which is evidently wrong.

Any coefficient not in the foregoing table may be found easily by addition. For instance, if

$k = 0.170$, and $w = 4\frac{1}{4}$; then L per foot run is:

$w = 4\frac{1}{4}$	$k = 0.090$	$L = 1$ oz. 10 dr.
$w = 4\frac{1}{4}$	$k = 0.080$	$L = 1$ „ 7 „
	$k = 0.170$	$L = 3$ oz. 1 dr.

In order to find k the following experiments should be made. In a mass with two free sides, and under normal conditions (for instance, an undercut coal seam, or a wall in a quarry), make a bore-hole of not more than 6 feet in length, charge it approximately and observe its effect. If it was too strong or too weak a charge, repeat the experiment with a modified charge, and so on, until two or three shots have been made, if possible at different depths, giving the full effect of the charge.

From the data thus obtained calculate, first, the weight of the explosive used per foot run, $\frac{L^1}{t} = L$, and then the coefficient k from the formula $k = \frac{L}{w^2}$; this gives, once for all, a measure of the force of the explosive under given conditions, from which the charge for all future shots can be determined by the charging table.

Suppose that from three blasts the following data have been obtained:

	Depth of Bore-hole.	Burden.	Charge.	Charge per Foot Run.
	t	w	L^1	$\frac{L^1}{t} = L$
1.	$3\frac{1}{4}$	$2\frac{3}{4}$	3^{10}	1^{2}
2.	$2\frac{1}{2}$	$2\frac{1}{4}$	1^{14}	0^{12}
3.	$4\frac{1}{4}$	$4\frac{1}{4}$	11^{1}	2^{11}

Now calculate the value of k from the formula $k = \frac{L}{w^2}$.

Or in a more simple way, find the burden in the charging table, and in the same line the weight most nearly corresponding to the charge per foot run; then the value of k will be found at the head of the corresponding vertical column. In this case, it is 0.150. It may be well to repeat here that the bore-hole, as a general rule, should not be made longer than the burden (Fig. 101).

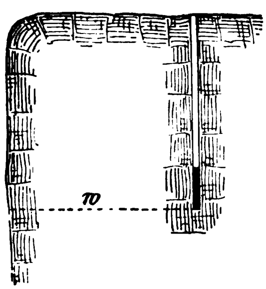


FIG. 101.

As in the majority of cases two free sides exist, the charging table has been calculated for those conditions.

If only one free face exists (the so-called breaking-in shots) the charge will have to be increased, the amount of increase varying with the angle of the bore-hole. For the theoretically best angle—about 48°—it should be taken at two and a half times the quantity in the table.

If there are more than two free faces the proper charge will be the following:—

For three free sides;	two-thirds	of the charge given in the table.
,, four ,, ,,	one-half	
,, five ,, ,,	two-fifths	
,, six[1] ,, ,,	one-third	

Of course all the considerations enumerated in the chapter on bore-holes must be remembered; for instance, that the radius of the breaking action is not equal to the radius of the fissuring action, and that, consequently, outside the crater formed the rock will be fissured and shaken to a certain distance so as to be easily broken down with mining tools. The specific gravity of the explosive must also be taken into account, and the width of the crater, especially when several shots are to act conjointly and towards one another. In this case a stronger charge might be given to the bore-hole that is fired first, so as to loosen the rock and give one more free side for the action of the others. In workings that are always driven in the same rock, and under the same conditions, the proper charge can be determined once for all; but if the conditions are continually altering it is not desirable to make fresh calculations at every charge, but to acquire (keeping the general rules always in mind) sufficient

[1] Isolated blocks or free stones.

experience by careful observations to be able to estimate rapidly the approximately proper charge as each fresh condition arises.

These estimates must not, however, be made in haste or superficially. Many miners have the following peculiar method of determining a charge: The depth of the bore-hole is gauged with the scraper and measured off with their hand (Fig. 102), the distance from little finger to the outstretched thumb being taken as 6 inches; and then, knowing the depth roughly, guessing how many inches of charge are requisite. This

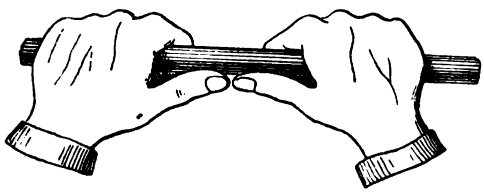


FIG. 102.

method shows that miners have found from experience that the quantity of charge depends on the depth of the hole; of course it is a very imperfect manner of determining a charge.

Most mistakes arise from such superficial estimates, and even experienced mining engineers have been misled by them. The diameter of the bore-hole, whether it has been drilled uniformly round or not, how much the charge is compressed, the specific gravity of the explosive, whether it is very quick, etc., are all influencing conditions, so that all of them should be carefully considered before estimating the charge; it is then more likely to be accurate.

As it is frequently impossible to take a pair of scales into the mine, an approximate measuring out of the charge may be made from the size of the bore-hole, etc. Thus a bore-hole made with a drill $\frac{7}{8}$ of an inch wide on the face is usually 1 inch in diameter at its lower end, and every inch of length of a well-compressed charge in it will correspond to 10 drams of blasting-powder, or 15 drams of kieselguhr or gelatine dynamite. In round figures a pint of loose blasting-powder weighs about a pound, the specific gravity of compressed powder is roughly 1.7, and of dynamite No. 1 or of gelatine dynamite, 1.6. A cartridge of dynamite No. 1, $\frac{7}{8}$ of an inch in diameter and $3\frac{1}{2}$ inches long, weighs $2\frac{1}{2}$ ozs., and a primer about $\frac{3}{4}$ of an ounce.

After the proper quantity of charge has been determined, care must be taken that it does not take up so much of the bore-hole as to leave an insufficient depth for tamping—a sufficiently deep and solid tamping is indispensable, if the explosive is to perform its work fully; for this reason there should always be at least 8 inches between the mouth of the bore-hole and the top of the charge. As a general rule, for bore-holes up to 3 feet in depth the charge should *not* occupy *more* than *one-half* the bore-hole for a powder charge, or *two-thirds* for a dynamite one. Within these limits, however, as has been before pointed out, it is frequently advantageous to fill as much of the bore-hole as possible with the charge. This can be effected by using smaller bore-holes, by using explosives of lower specific gravity or of less strength, such as the lower-grade dynamites, for instance.

CHAPTER X.

FIRING.

a. **Straw and Fuse Firing.**—If straws are used for firing, or if the fuse is too short, or the distance the miners have to go to reach a place of great safety is long, a sulphur match (*i.e.* woollen threads that have been dipped in melted sulphur) is used to ignite the fuse or straw. It is attached to whichever kind is employed by slightly warming one end in the lamp. In ordinary cases the fuse is slit lengthwise for about half an inch, and the sides opened out so as to expose the core of powder (Fig. 103); it should be fired by a slow-match and never by a lamp, because with a flame the tarred coating is ignited and continues to smoulder, giving off objectionable fumes. In damp bore-holes the so-called double or sump fuse, which is not affected by moisture for some time, should be used.

FIG. 103.

If a considerable period of time elapses between charging and firing, gutta-percha-covered fuses should be employed. In case these cannot be readily obtained, ordinary fuses may be waterproofed by dipping them in the mixture proposed by General Hess for waterproofing cartridges (see page 110), or by dipping them in tar alone, or by smearing them over with tallow, etc.

The detonator should be as strong as possible; the No. 5, containing 0.8 gramme of fulminate, is the best for ordinary use, as, especially with long charges, the effect of the shot is materially increased by a powerful initial impulse, while the use of weak detonators is bad economy.

A person in whom reliance can be placed should always have control of the charging and firing. He has to note the number of holes fired and to count the reports; the other miners should do this as well—for two charges frequently explode simultaneously—in order to make sure that they have all exploded. It is advisable to wait at least ten minutes before returning to the working face to allow the fumes to disperse somewhat, as it is injurious to inhale the fumes—even the least noxious ones—from any explosive.

A pause before returning is still more imperative, if it is not absolutely certain that *all* the charges have been successfully fired; for if there has been a missfire, it may be due to a fuse not having been properly ignited, and as it may be still glowing, the charge may explode after a long pause. It is far better to wait too long than too short a time.

It may be again pointed out that, by using fuses, single shots may be made to explode first, and thus form additional free faces to assist the effect of the others.

In a heading like the one shown in Fig. 104, for instance, the breaking-in shot, 1, would be fired first; then the enlarging shots, 2, 3, 4, and 5, which are arranged around 1; then the roof shot, 6; then the wall shots, 7, 8, 9, and 10; and finally the floor shots, 11, 12, and 13.

b. **Electrical Firing.**—1. **General Considerations.**—Where a number of shots are to be ignited simultane-

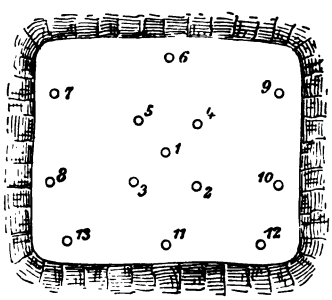


FIG. 104.

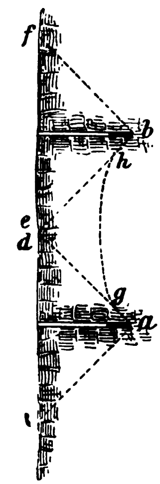


FIG. 105.

ously, electrical firing can be adopted with great advantage. It is, of course, necessary that the breaking-in shot should be fired (by a fuse, if there is only one, or electrically if there are more) first, and that the next group of shots that is fired be the one next to the free side produced by the breaking-in shot, and so on, the firing of each group producing a fresh free side for the group following.

Though in large workings some time will be lost in adjusting the circuits, it is compensated for by the better effect obtained, and the smaller number of bore-holes necessary. In Fig. 105 are shown two craters formed by charges which have been properly proportioned and placed, and which have been fired by fuses; it will be seen that the bounding lines meet at an acute angle, leaving the rock between the two craters untouched by the two charges, whose effect has been simply the formation of the two craters *a c d* and *b e f*. If the two charges are fired absolutely at the same instant, the effect of each reaching the bounding surface at the same time will have a combined action sufficiently great to break down the rock between the lines *b e* and *d a*, and a single crater of the form *c a g h b f* is the result. Therefore, when shots are to be fired singly they must be spaced nearer together in order to break out the rock between than when they are to be fired simultaneously. Hence, when electrical firing is adopted, the shots can be spaced further apart, and, consequently, a less number of bore-holes are required to effect the same work. A rule that will hold good in all cases for the spacing of such simultaneous shots cannot be given, but on an average the crater-radius may be increased by *one-half*; it depends, however, upon the nature of the rock, and must be determined by a few trial shots.

2. **Electrical Detonators.**—There are three types of electrical detonators—(*a*) the *slot* detonator; (*b*) the *incandescent slot* detonator; and (*c*) the *incandescent* detonator.

The slot detonator has already been described (see page 69). It is largely used, and requires a high tension current to ignite it.

The incandescent slot detonator is similar to the slot form, except that the priming composition is so composed as to be slightly conductive. By this means the priming composition favours the formation of a series of sparks, which can be induced at a very low tension. The incandescent slot detonator illustrated in Fig. 106 (from the Electric Fuse Factory at Cologne) is made of two strips of metal, separated from each other by means of a strip of cardboard. These strips are dipped into the priming composition. The conductors are soldered on to the strips, and the whole is embedded into sulphur composition, and then fixed into a case, which receives at its lower end the detonator.

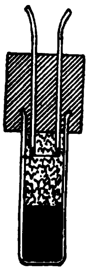


FIG. 107.

FIG. 106.

The incandescent detonators (Fig. 107) are made similarly to the slot detonators, but the ends of the terminals projecting into the priming composition are connected by a very fine platinum wire. When a current is passed, this wire, on account of its large electrical resistance, becomes red hot. This detonator has the disadvantage of requiring currents of great intensity, though of low tension; on the other hand, they present the great advantage that the conducting wires need not be carefully insulated, and can even be left bare.

3. **Firing Machines.**—Slot detonators are usually fired by frictional machines, influence machines not being so convenient and requiring more scientific knowledge for their handling.

Induction apparatus (battery cells and an induction coil) would have the advantage of cheapness, and as they give a powerful current of high pressure, would enable a large number of shots to be fired simultaneously.

Recently, dry batteries have been introduced in Germany for firing low-tension fuses. They have the advantage that their action does not depend on a momentary spark or glow, but that a continuous current can be sent through. On the other hand dry cells have only a limited duration, and may give way at any moment, so that they require to be constantly checked and kept in repair. When a large number of holes have to be fired from a great distance, the number of cells required becomes so large that the battery is no longer portable. If only a medium number of shots have to be fired together, a hand magneto- or dynamo-electric machine is useful. Either is very certain in its action, and is not affected by dampness; but, with incandescent detonators, twelve is probably about the maximum number of shots that can be fired by a machine that is sufficiently portable for use in mining work.

Frictional machines are very sensitive to damp, and it is easy to break down the condensers by working the machine too rapidly. They have, therefore, to be kept in dry places and to be frequently tested, or one is likely to find just when they are wanted that they are temporarily useless. Nevertheless, they are fre-

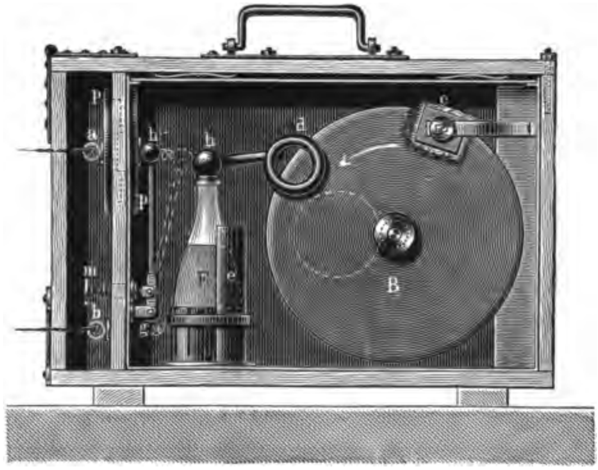


FIG. 108.

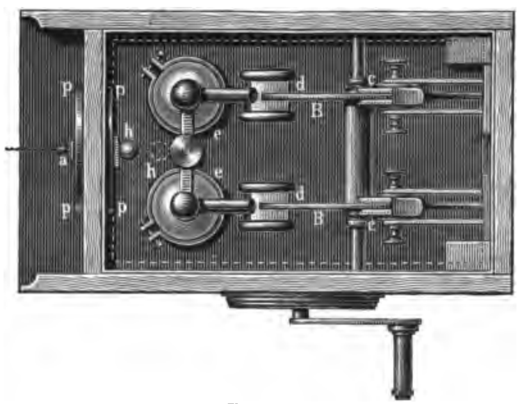
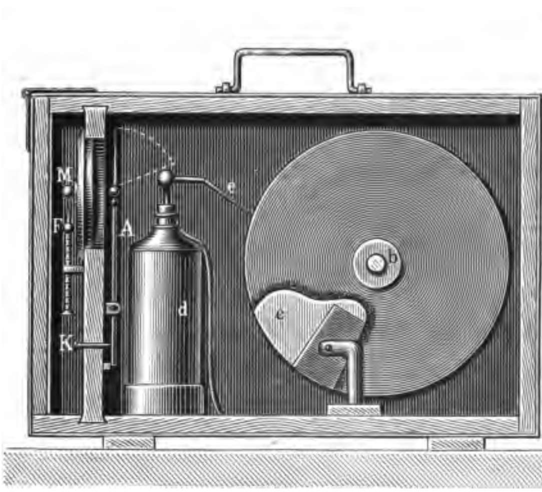


FIG. 109.

quently used, as their manipulation is simple, the detonators required are easily obtained, thin conducting wires may be used, and as many as forty shots may be fired simultaneously even from a great distance.

The frictional machine of *Bornhardt*, of Brunswick (Figs. 108 and 109), consists of two ebonite discs, B, which can be rapidly rotated by a wheel and pinion; the two rubbing pads, *c c*, made of cat's skin; and two Leyden jars, F. The positive electricity set free is collected by the combs, *d d*, and accumulated by the Leyden jars. By pressing the knob, *m*, the discharger (which is connected near *g* with the outer coating of the



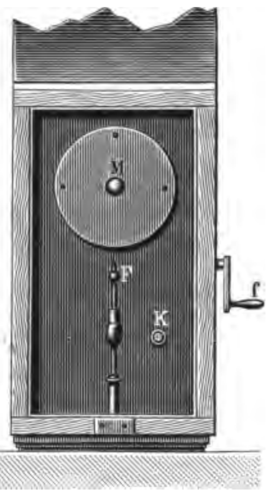


FIG. 110. FIG. 111.

Leyden jars, the upper knob being connected to the contact ring, *a*) is brought into connection with the terminals, *h h*; the rest of the arrangement will be easily followed from the illustration. The apparatus is enclosed in a sheet-iron box, and this again in a wooden one with a layer of slightly burnt charcoal between them to absorb moisture. With the Bornhardt machine the handle may be turned in either direction; indeed, an occasional change of the direction is recommended. The machine may be depended on to fire from thirty to forty shots at a time. Before using it the small chains at the side are hung to the contact rings, *a* and *b*, when, on making twelve to fifteen revolutions with the handle and pressing the discharging knob, sparks should pass between all the fifteen metal buttons placed in a row on the side. A similar machine is made by the Nobel Dynamite Company at Vienna (Figs. 110 and 111). It has a different discharger, however, and a switch by which the two contacts are kept short-circuited until the moment of firing, so that a premature discharge is impossible. It is enclosed in a wooden box, and, from the position of the rubbing pads, can be turned in one direction only.

The magneto-electric blasting machine, made by *Breguet*, of Paris (Fig. 112), consists of a horse-shoe magnet, N O N, with two coils of insulated wire, E E, wound on iron cores, one being fixed at each pole; across the outer end of these cores is a soft iron armature, A A, hung by a hinge at its lower edge. By striking the knob, B, the machine is suddenly pulled away from the magnet coils and a powerful current is induced in the bobbins, E E, which passes from the terminals into the outside circuit. The spring R at once short-circuits the coil, and the current circulating in the coils reinforces the magnets until contact is made at S. This apparatus will fire about eight bridge or incandescent detonators simultaneously.

Bürgin, of Bâle, has designed a mine-firing machine (Fig. 113) which has been adopted by the Swiss Corps of Engineers. It is a small dynamo machine on the Bürgin system, the armature being driven by a handle through a double pair of spur gears. When a sufficiently strong current has been set up, a small soft iron

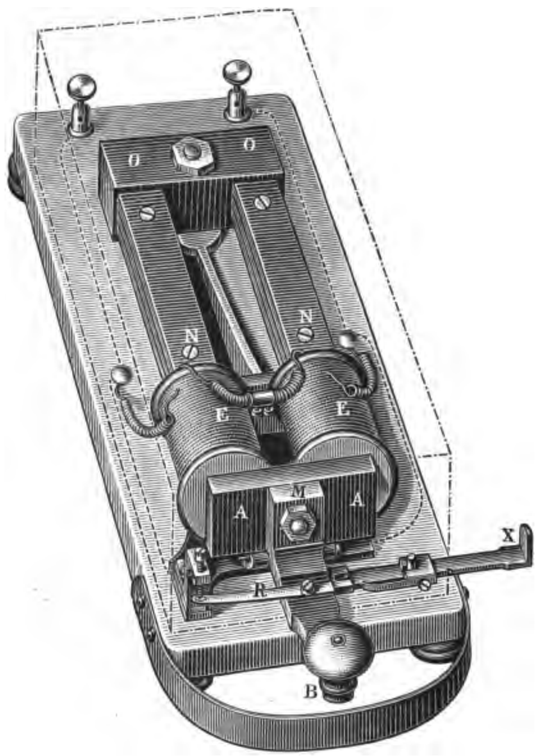


FIG. 112.

armature is pulled over by the field magnets which breaks the circuit, and the so-called "extra current" thus set up is led into the firing circuit. Bürgin's machine can be used both for slot and incandescent detonators, either in parallel or in series; it will easily fire forty shots simultaneously.

A magneto machine sold by *Alois Zettler*, of Munich (Fig. 114), consists of a small magneto generator, similar to those used for ringing-up in telephone systems; the H-armature of it is wound in a peculiar manner and gives alternating currents. It is said to do excellent work. According to experiments made by Prof. Carl, it will fire as many as eighty detonators arranged in parallel; its weight is only about 15½ lbs.

A form of firing machine much used now is shown

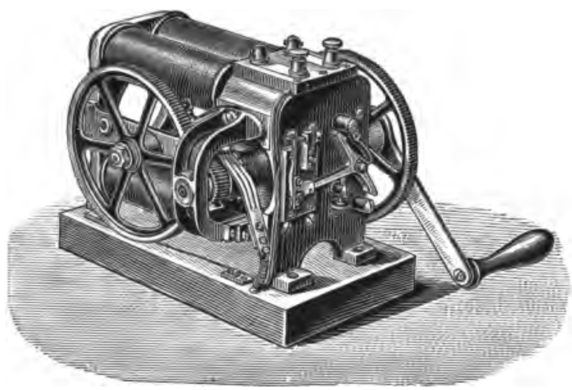


FIG. 113.

in Figs. 115 and 116. It consists of an electro-magnet, A, between the poles of which a cylindrical armature, B, rotates. The armature is driven by a rack and pinion, B and C, the current thus generated being rectified by a commutator, F. The armature is short-circuited by the key D and E, until the rack in descending breaks this short circuit, and the current then passes into the firing circuit through the terminals. It is a very handy and cheap apparatus, and will fire about twelve shots simultaneously.

A similar machine, made by the Fabrik elektrischer Zünder of Cologne, is shown in Fig. 117.

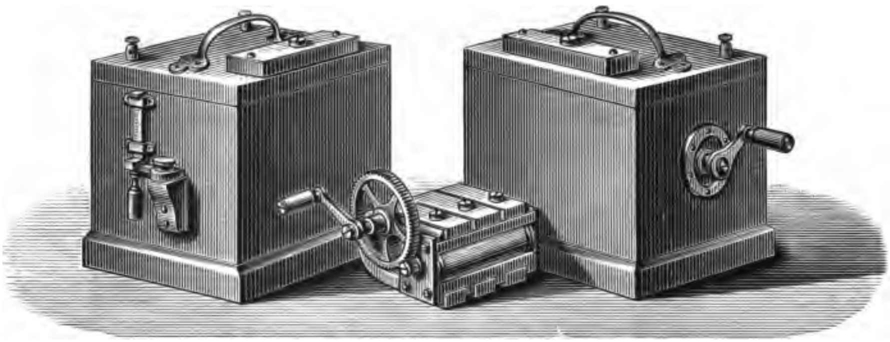


FIG. 114.

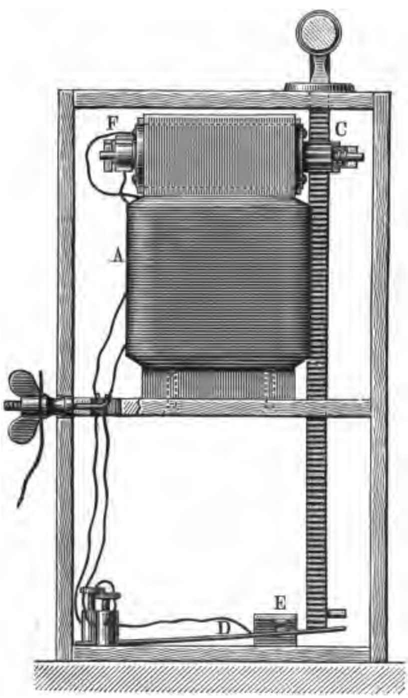


FIG. 115.

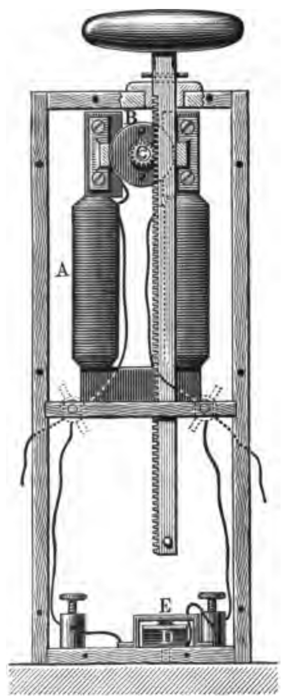


FIG. 116.

4. **Circuits.**—It is most desirable that a complete metallic circuit be used, as, if an earth return is adopted, the firing becomes less certain, and there is a loss of current. With frictional machines supplying currents of very high tension the material used for conductors is of little importance. The author has fired ten shots simultaneously from a distance of 2000 feet with iron conducting wire only $\frac{1}{64}$th of an inch in diameter; but going to such extremes is not to be recommended in practice—it is always best to be on the safe side.

FIG. 117.

The number of shots that can be fired together becomes smaller the greater the total resistance in circuit. This consists of the resistance of the air-gaps in the slot detonator (this, unfortunately, cannot be reduced below a certain limit, depending on the method used in cutting the slots), and the resistance of the conductors, which depends on their sectional area, their length, and on the material from which they are made. Taking the electrical resistance of copper as 1, then (according to v. Waltenhofen) that of brass is 4.04, of iron 7.11, and of platinum 9.20. The use of copper conductors is, therefore, always advisable. With a Bornhardt frictional machine, fitted with two condensers, copper wire of from $\frac{1}{16}$th to $\frac{1}{32}$nd of an inch in diameter is sufficient for distances up to 1200 feet with thirty revolutions of the handle.

With magneto machines and batteries, wires of at least 0.066 inch diameter should be taken for distances up to 600 feet. The diameter of the wires has to be increased for greater distances; thus, for 800 feet 0.076 inch, for 1000 feet 0.085 inch, and for 1200 feet 0.093 inch should be used.

The author would strongly advise the fixing of a permanent main conductor, and a small recess being made to shelter the miners and for the storage of the firing apparatus. It seldom happens that such a permanent conductor cannot be arranged for, as it is nearly always possible to erect poles and fix insulators into the rock, or the conductors can be carried in wood casings, if necessary. The loss of time occasioned by winding and unwinding long lengths of conductors and disentangling wires is the chief reason why miners look upon electrical firing with disfavour. The permanent part of a circuit should be carried on porcelain insulators from the firing recess to near the place where the blasting is to be done, so as not to be liable to damage thereby.

If the mine is dry and does not contain any metal, bare wires may be used, provided they are tightly stretched and are kept at least 2 inches from the rock and 8 inches from each other. In all other cases, including main circuits in the open air, wires with an insulating covering of india-rubber should be used; double cables are preferable, as they are less likely to be damaged and require fewer insulators.

If frictional machines are to be used, the arrangement or coupling-up of the detonators can only be made in series (Fig. 118). When dynamo machines are used, the detonators may either be coupled in series as above; in parallel, as shown in Fig 119; or in a manner combining both systems, series and parallel (Fig. 120). With the series arrangement one faulty

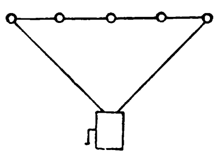


FIG. 118.

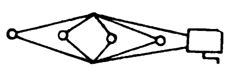


FIG. 119.

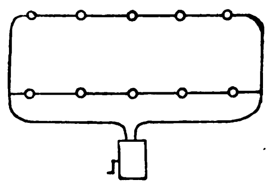


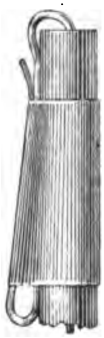
FIG. 120.

detonator will prevent all the others following it being fired; in the parallel arrangement each detonator is quite independent of any of the others. With the charge arranged in series it may happen that one out of a row of detonators misses fire; this may be caused by the slot in the detonator being too wide, by the circuit being too long, by the machine not having been worked long enough to properly charge the condensers, or by the faulty working of the firing machine. If this happens, the detonators that have missed fire should again be connected with the machine, and on a second attempt they will probably explode without trouble.

The connecting of the wires has to be done very carefully. In the main circuit a proper joint should be made by cutting off the insulation, scraping the uncovered ends clean and twisting them together; if possible, they should also be soldered together. The joint is then insulated by wrapping a thin strip of gutta-percha round it, or covering it with Chatterton's compound; failing these, a strip of cotton tape dipped in beeswax may be used. The insulation is made secure by binding the joints over with fine brass wire.

The two ends of the main circuit should terminate on a plank, and have rings or terminal screws attached so that the wires from the bore-holes may be connected by simply hanging them on to the terminals or rings. The connection between the ends of the main circuit and the bore-holes should be made with thin soft brass or annealed iron wires, in as direct a line as possible. If the distance is great or corners have to be turned, wooden pegs driven into the walls should be used to support the wires, and a turn or two made round each peg. First, the individual shots must be connected, care being taken that the wires do not touch the ground anywhere or each other; this may be avoided by letting them rest on small blocks of dry wood. Where a crossing of the wires cannot be avoided a piece of wood, at least 4 inches long, should be placed between them.

If the connecting wires do not touch the ground anywhere, no insulation is necessary, but care must be taken in making the joints that no projecting ends are left. When all the shots are connected the two free ends left have to be connected to the terminal screws or rings on the ends of the main circuit, or, if there is no permanent circuit erected, to the terminals of the firing machine.



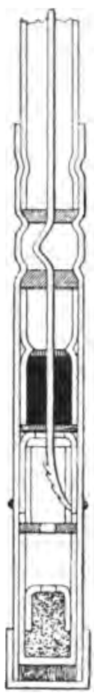


Fig. 121.

Care must be taken that the last connection, by which the detonators are placed in circuit with the *machine*, is not made until *all* the detonators have been coupled and all the miners have retired to a place of safety.

There is always a certain charge remaining in the condensers, which with carelessness might cause a premature explosion. For the same reasons the ganger should allow no one to touch the handle of the firing machine, and *before* connecting the machine to the circuit should discharge it by coupling the testing buttons, by means of their chains, with the machine, and depressing the charging knob.

Even with electric firing it is not advisable at once to approach a missed shot. Cases have occurred where a charge has gone off after a considerable time, not through any secondary electric action, but probably through a faulty detonator having failed to explode the charge in the first instance. This becoming ignited by the priming composition, finally exploded.

c. **Substitutes for Electrical Firing.**—One substitute for electrical firing is the friction fuse (Figs. 121–123) invented by General John Lauer. It consists of a brass tube in which is inserted another brass tube containing a priming composition of potassium chlorate and antimony sulphide. A friction wire, jagged at the end and guided by paper rings, lies in this mixture. At the end of the tube there is a detonator. The priming composition is ignited by pulling the wire,

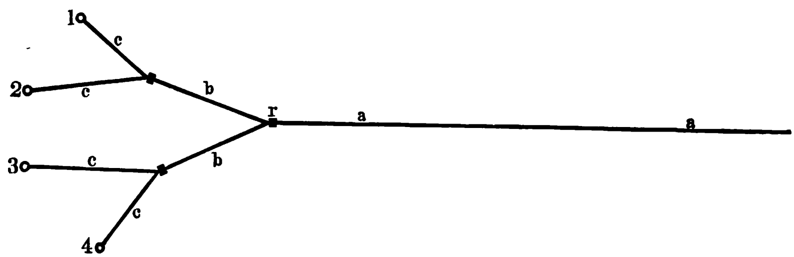


FIG. 122.

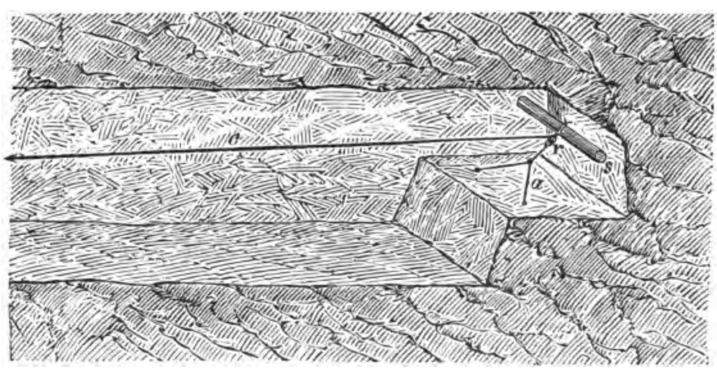


FIG. 123.

and this in turn fires the detonator. The friction fuse is placed on the charge like an ordinary detonator and the individual shots all connected to a cord, carried over pulleys, nails, pegs, or other similar guides, to a place of safety, from which the charges can be fired by pulling the cord. The cords connecting the different shots to the pulling cord should be uniformly tight, so as to avoid any missfires.

Another fuse, which has found much favour, is Tirmann's percussion fuse (Fig. 124). It consists of a metal case, *A*, with a detonator, *G*, inserted at the bottom, and a cork, *J*, on the top. A hooked wire, *D*, carries the steel striker, *C*, and is held in position by a steel spring, *B*. A cardboard disc, *E*, and a steel ring, *F*, keep the whole tight. On drawing out the wire, this stretches first and cuts the cardboard disc, and is then drawn out of the striker, thereby liberating the latter. The striker is shot forward, and detonates the fulminate. Tirmann's fuse has proved to be perfectly safe in fiery mines, and the percentage of missfires is not more than 0·05 per cent. The pull required is about 34 lbs., consequently the fuse can stand a good deal of rough handling.

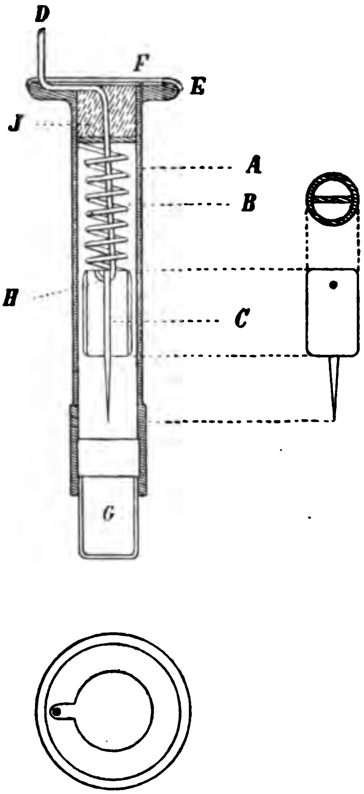


FIG. 124.

A detonating fuse, invented by General Philipp Hess, and adopted by the Austro-Hungarian Corps of Engineers, deserves full explanation. It is made by drawing cotton

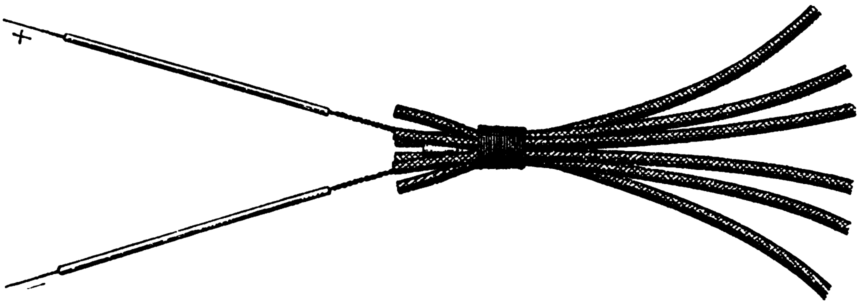


FIG. 125.

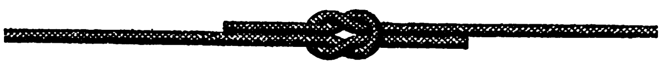


FIG. 126.

FIG. 127.

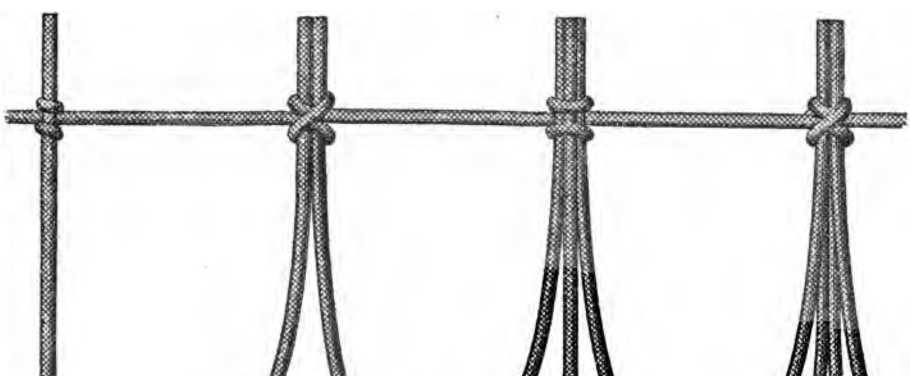


FIG. 128.

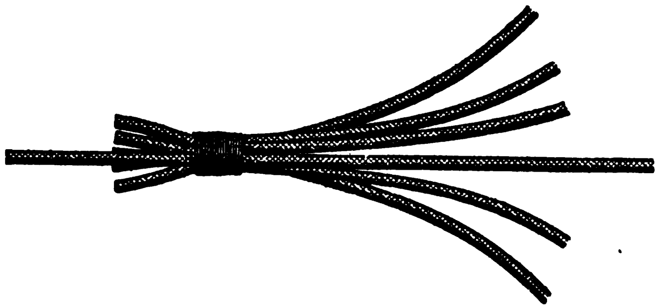


Fig. 129.

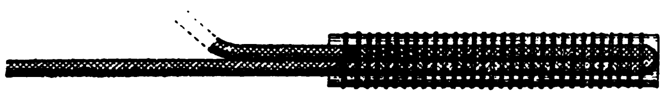


Fig. 130.

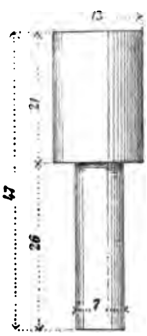


Fig. 131.

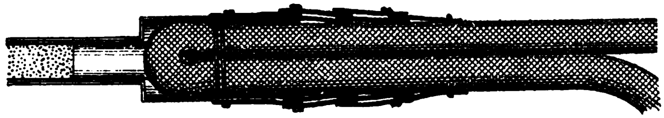


Fig. 132.

threads through a paste of fulminate of mercury, and afterwards covering them with a protecting coating of some suitable material. With this fuse no detonators are required, as the end may be put into the dynamite cartridge itself. The coupling of several charges for simultaneous firing is effected by simply knotting the different pieces of fuse together (Figs. 125–132). A free end is inserted into one end of a metal socket, and an ordinary safety-fuse and detonator into the other. As this detonating fuse transmits the explosion at the rate of 5500 yards per second, the various charges are fired simultaneously.

The firm of Bickford Smith & Co., of Tuckingmill, make an instantaneous fuse, which differs only from their safety-fuse in having a core of cotton wick that has been drawn through a paste of meal powder instead of a powder train. To fire several shots simultaneously by this fuse, the required number of fuses are inserted into a tin socket, at the other end of which is a gunpowder disc and a perforated wood plug to take the safety-fuse for igniting; the whole is insulated with gutta-percha. This instantaneous fuse burns at the rate of 150 yards per second, and its only disadvantage is that the number and the distance apart of the shots must be known beforehand so as to be able to order the fuse, already connected up, from the makers, as this cannot well be done at the mine. In workings or tunnels that are advanced at a uniform rate, as, for instance, by machine drilling, it may be adopted with great advantage.

CHAPTER XI.

RESULTS OF WORKING.

THE reader will, of course, expect to find a large amount of exact data from which he will be able to form opinions of the probable effect of any proposed blasting operation. It would be very easy to give an almost endless array of figures relating to effects obtained at various places, but nothing would be more confusing. This will be evident to those who realise that not only are the natural properties of rock nearly everywhere different, but that the size and shape of the workings have a very considerable influence on the firmness with which the working face is bound to the main body of the rock; and that the economic considerations as to the time of advancing, the size of the blocks desired, the skill of the workmen, and the variations in cost of labour and materials at different places, all have an effect on the most suitable manner of working. It will be evident that it is impossible to give fixed rules that will be universally applicable; all that can be done is to give broad outlines of average results obtained by experience. Those who are occupied in the midst of blasting work can see with little trouble the results obtained around them; and those who have to undertake a blasting operation must either determine the proper method experimentally on the spot, or (being guided by previous experience) depend upon their own judgment.

The average work per hour can be taken as:—

	Hand-boring with cast-steel tools. Bore-holes of 1 inch.	Machine drilling. Bore-holes of from 2½ to 3 inches.
In ironstone . . .	7¼ inches	36 inches
„ granite . . .	16 to 24 „	80 „
„ greywacke . . .	20 „	80 „
„ slate	24 „	100 „
„ limestone and dolomite .	28 „	100 „
„ quartz (mild) . . .	32 „	120 „

In the above, allowance has been made for resting and cleaning out the bore-hole.

These figures are only to be taken as broad averages, because the force required (and, therefore, the time taken) depends very materially on the direction of the bore-holes. This is well shown by the experiments of Prof. Höfer with bore-holes, slightly over an inch in diameter, in the greywacke of Příbram.

Direction of the bore-hole.	Time in seconds required for 1 inch of bore-hole.
85° downwards	152
60° „	188
52° „	241
27° „	282
2° „	257
0° „	323
24° upwards	345

Jarolimek, when experimenting in the dolomitic limestone of Raibl, found

Direction of the bore-hole.	Time in seconds required for 1 inch of bore-hole.
60° downwards	193
10° upwards	287
45° ,,	345

The consumption of explosives varies through a still wider range, and it will, in general, become smaller the wider the working place is. The consumption in mine headings per cube yard of rock may be estimated as follows :—

	Dynamite No. 1.	Gelatine dynamite.	Blasting gelatine.
Gneiss and greywacke	3.400 lbs.	2.900 lbs.	2.400 lbs.
Limestone	2.500 ,,	2.100 ,,	1.700 ,,
Sandstone	1.700 ,,	1.450 ,,	1.200 ,,

In coal, between 2 and 3 ounces of dynamite No. 2, or between 3 and 4 of dynamite No. 3, according to the toughness of the coal, are required per cubic yard. In giant mines a consumption of from 3 to 4¾ ounces of dynamite No. 3 per cubic yard of rock has been observed. In railway work, where time is an important consideration, the consumption of explosives is much higher. With machine drilling, where the most favourable position for the bore-hole cannot be secured, it increases still more. On the St. Gotthard Tunnel works, in driving the gallery from the Airolo side, 7.05 lbs. of dynamite No. 1, or 4.72 lbs. of blasting gelatine, per cubic yard, were used for advancing the heading, and 3.37 lbs. dynamite No. 1, or 1.72 lbs. of blasting gelatine, per cubic yard, for enlarging, the rock being mica-gneiss. On an average, 5 detonators and 12 feet of fuse are required for each pound of dynamite; with deep holes the former number becomes smaller and the latter larger, as a matter of course.

The most difficult data to give are those relating to cost of working. In English mines the following are about the average:—

In rock of the hardness of	Gneiss and greywacke	30*s.*	per cubic yard of rock;
	Limestone	24*s.*	
	Sandstone	18*s.*	

including blasting material, lights, and the repairing and sharpening of tools.

CHAPTER XII.

VARIOUS BLASTING OPERATIONS.

a. **Quarrying Building Material and Freestones.**— The object aimed at in quarrying these is to shatter the rock as little as possible, and in the case of freestones, even to break it without any injury. For quarrying building stones the bore-holes are made very deep, up to 10 feet or more, with a corresponding

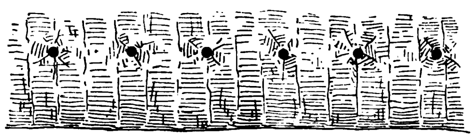


FIG. 133.

task, and spaced rather widely apart; the lower grade dynamites are the most suitable explosives to use. If the rock is to be broken in very large blocks, and nothing at the back of the bore-hole injured, only gunpowder or the weakest class of dynamite ought to be used, and the charge made so small that the rock is not thrown down, but only sufficiently cracked away from the main body to enable it to be easily removed with crowbars, etc. To obtain ashlars, plates, etc., bore-holes are spaced equally in a row or drilled along the required line (Fig. 133); they are then filled with water, and half a cartridge of gelignite is placed *on the top* of each, and all fired simultaneously by electricity; the block ought then to break away uninjured. Granite plates, 17 feet long and 8 inches thick, have been obtained in this way. If a larger block has to be broken up, a hole should be drilled at its centre,

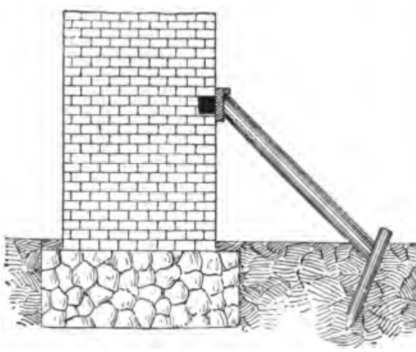


FIG. 134.

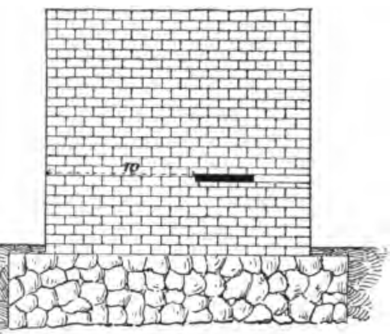


FIG. 135.

filled with water, and a half cartridge exploded on the top.

b. **Blasting of Masonry.**—A number of blasting operations occurring in some industries and certain agricultural work will be described here. A broad indication only of the methods to be adopted is required, as, in most such cases, great economy in explosives is not, as a rule, very important, and any one who has a large number of such operations to execute will easily be able to make more accurate calculations from what has already been said.

Walls under 5 feet in thickness are more easily destroyed by manual labour than by blasting; if rapidity is aimed at, however, blasting may be adopted. Cavities are chiselled out above the foundation (Fig. 134) into which gelignite is placed, the cartridges being either tied together in bundles or pressed into small wooden boxes. The distance apart of the cavities should be twice the thickness of the wall; a tamping is formed by a piece of stout board supported by a strut from the ground. The formula for calculating the

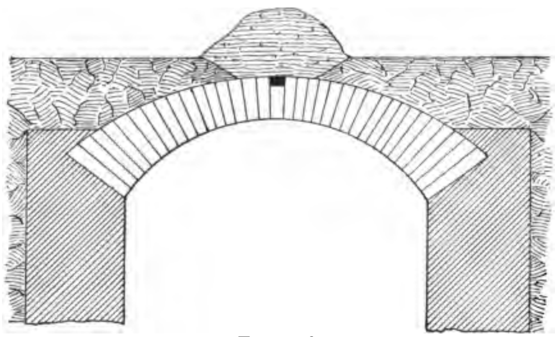


FIG. 136.

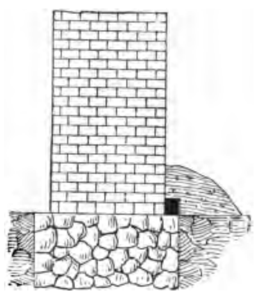


FIG. 137.

charge is $L = \frac{1}{10}d^2$, where L is the weight of the charge in pounds and d the thickness of the wall in feet. Simultaneous firing, by electricity, of all the charges along the wall is very advantageous and diminishes the risk of accidents. Walls over 5 feet in thickness and retaining walls are destroyed by bore-hole shots. Bore-holes are driven to the centre of the wall, and the charge calculated from the table on page 134, where w = half the thickness of the wall. If the bore-holes do not penetrate half through the wall, then w must be taken as the distance of the charge from the opposite face of the wall to the mouth of the bore-hole. For loaded walls the bore-holes must be made closer together.

The most effective way of destroying masonry arches is to cut a groove right across the top of the arch at its centre; a roll of dynamite is laid along this groove and the charge tamped with about 2 feet of earth (Fig. 136). In exceptional cases where a wall has to be destroyed very quickly, a much more powerful charge may be laid along the foot and well tamped with earth (Fig. 137);

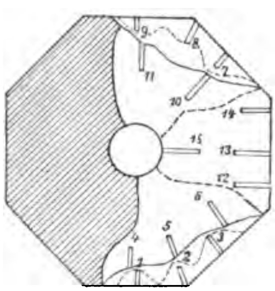


FIG. 138.

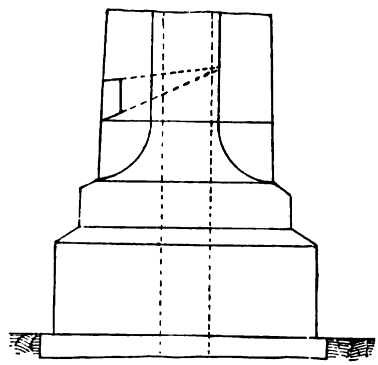


FIG. 139.

the amount of explosive that has to be used is, however, considerable if the effect is to be certain.

To throw down large brick chimney-stacks, radial bore-holes are made at the base of that side towards which the chimney has to fall; Figs. 138 and 139 show the position of the bore-holes very clearly, and are from an actual blast performed by Lieutenant Wiber near Aszód.

c. **Blasting of Iron Structures.**—The total destruction of large iron structures by blasting is a very rare occurrence indeed in civil engineering. When it has to be done, the charges should be tightly bound against the joints. When gelignite is used the charge may be calculated from the formula $L = \frac{bd^2}{9}$ for cast-iron plates, and $L = \frac{2bd^2}{9}$ for wrought-iron plates, where b and d are the width and thickness of the plate respectively in inches and L the charge in pounds. The *minimum* value of b that can be taken is 6 inches. The charge is distributed uniformly over the whole width of the plate, which should break clean through. For a cast-iron column the charge is fixed on its base and tamped with earth; it may be calculated from the formula $L = 100d^2$, where d is the diameter in feet and L the charge in pounds as before.

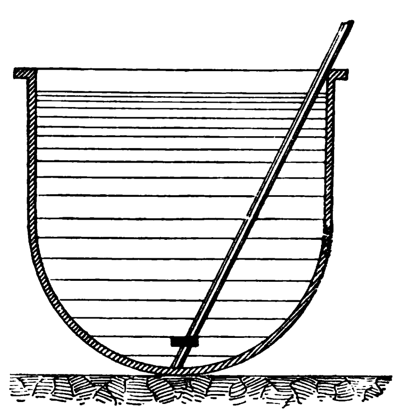


FIG. 140.

Old castings, boilers, retorts and similar hollow pieces may be broken by filling them with water, and placing the charge—which must be waterproofed (see page 110)—near the bottom by tying it to a rod or letting it down by a string (Fig. 140). Four ounces of gelignite used in this manner are sufficient to break up a cast-iron hemispherical pan 6 feet diameter at the top and $1\frac{1}{4}$ inches thick. If the piece to be broken has no cavity, holes must be drilled to receive the charge, and if the proximity of buildings make it necessary to take special precautions, only feeble charges should be used, repeating them until the breaking is effected.

d. **Blasting Wooden Objects.**—Single posts should have the charge laid on in prismatic form. The formula for the charge is $L = \frac{d^2}{25}$, L being the weight in pounds and *d* the diameter of the post in inches. The same formula may be used for blasting trees; only, if a single hole is drilled, the wood would be splintered a

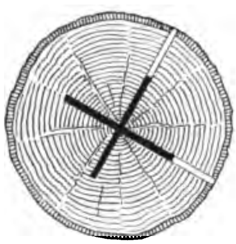


FIG. 141.

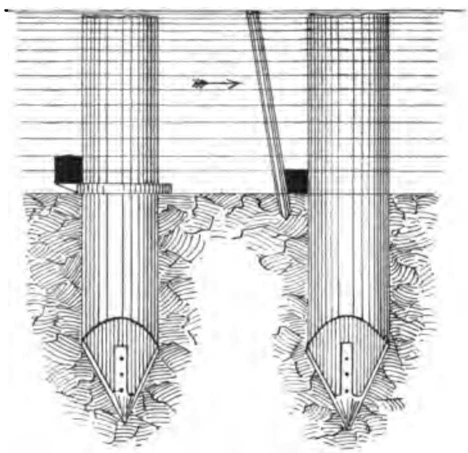


FIG. 142.

good deal. Large trees may be broken very cleanly by drilling two intersecting holes at right angles; both holes are charged and tamped; but, of course, only one detonator and fuse is required (Fig. 141).

If large pieces of timber—such as piles—have to be destroyed under water, a waterproof charge (2 pounds for piles from 12 inches to 16 inches diameter) is laid in close contact with the pile. To make sure of this, the charge may be fastened to an iron hoop, which can be slipped down over the pile in such a manner that the current of the water will press the charge against the pile (Fig. 142); or it may be bound to a pole which can be driven down in the ground close to the pile (Fig. 142). If the pile has to be broken below the ground-line, it may be drilled to the required depth by an auger, and the hole charged as an ordinary bore-hole. In exceptional cases a series or group of piles can be destroyed by one or several charges of dynamite, which need not necessarily be in contact with the piles; but in such cases very large charges are required, which increase as the number of piles and the distance of the charge from them becomes greater.

The blasting of tree stumps and roots can only be economically done with the harder woods. Soft woods are too elastic, and the quantity of charge required is out of all proportion to the value of the wood obtained. The first step is to cut through the root-branches with an axe. Then the charge is filled into a hole drilled, in smaller stumps, from the top surface into the main root; with larger ones the holes are drilled crosswise, as previously described, or a set of radial holes are drilled towards the main root, and the charges fired electrically.

e. **Blasting in Earth.**—Such operations have sometimes to be done where the ground is difficult to work with a pickaxe, or is frozen. A series of holes is made in the ground by means of a pointed iron bar, which has an eye at the upper end, into which another bar can be placed for withdrawing it. These holes are then charged and tamped in the ordinary way.

The charge can be calculated from the formula $L = ct^3$, where L equals weight of charge in pounds; c equals coefficient of effect, and t the depth of the hole; the distance between the holes should not be more than twice the depth. In a similar way fertile soil that is too hard for ploughing may be loosened, or an impermeable stratum may be broken through to give access to water, or, as is done in the oil-wells of Pennsylvania and Galicia, a temporarily better outflow may be obtained by exploding a strong charge of dynamite at the bottom; this is generally called *torpedoeing*. An exactly opposite effect is sometimes obtained in grass soil or other easily compressible ground, when it carries so much water that excavating for foundations is rendered difficult. Holes of from 3 to 10 feet depth are driven into the ground, and a dynamite charge occupying at least half the depth exploded in them; an enlarged well is thus obtained, into which open sheet-iron cylinders are dropped, and concrete filled in. As the concrete is being filled in, the cylinders are gradually withdrawn. According to the nature of the soil, the walls which have been strongly compressed by the blast will resist the action of the soil-water behind them for from one to two hours, during which time all the work has to be done. This process was devised by Bonnetoud.

f. **Blasting under Water.**—The difficulty of working under water increases considerably as the depth increases, and with the force of the current, if there is one. Blasting operations on an extensive scale (for instance, the removal of large obstructions to shipping) require, of course, a very careful consideration of all the existing conditions, so as to devise the most suitable method of working. In the improvements of water-courses and rivers, of which the removal of rapids is the most common, or the lowering of its bed, a temporary bridge may be thrown over the river, or with greater width a barge anchored, to provide a working platform. On the side of this platform two iron brackets are fixed at a suitable distance apart, with holes in them to guide the boring-bar, which is passed through them (Fig. 143), and a series of holes, within a limited circle, drilled without moving the platform. In a similar way a scaffolding may be used if the blasting is to be done close to the river bank. In deeper rivers a larger platform will have to be provided, and possibly fixed on a number of pontoons in such a manner that it can undulate as little as possible, and machine drilling adopted. In order to relieve the pressure due to the current, from the boring-bar, the water must either be stemmed back, an iron tube slipped over the bar, or even a wooden channel, or some angle-iron, placed a few inches up stream from the bar. Before charging a bore-hole an iron tube is placed over it and the cartridges slipped down through it into the bore-hole. The column of water is usually sufficient tamping; but if it is less than 20 inches deep, dry sand should be run into the bore-holes through the iron

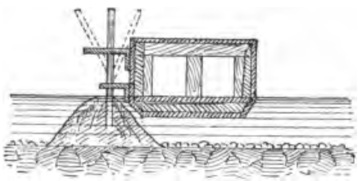


FIG. 143.

tube to make sure of the work; it is best to fire such bore-holes electrically. Dynamite is generally used, as gunpowder requires very elaborate precautions to be taken, and even then gives inferior results; the dynamite should be put into boxes of tin or cardboard, dipped in melted paraffin wax. If rapidity is an important object, and there is no time for making special arrangements, or where, as in the case of deep-sea work, they would be too costly, it is simplest to use comparatively large charges of dynamite placed at suitable distances on and round the object to be destroyed; if there are any existing cavities in it, natural or otherwise, the charges should always be placed in them (Fig. 144). Although with this method of blasting the consumption of dynamite is very considerable, the total cost will generally be much less than if drilling had been resorted to.

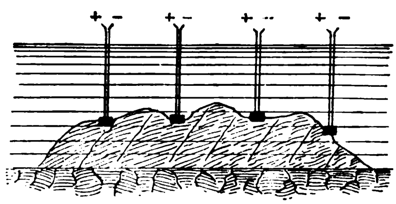
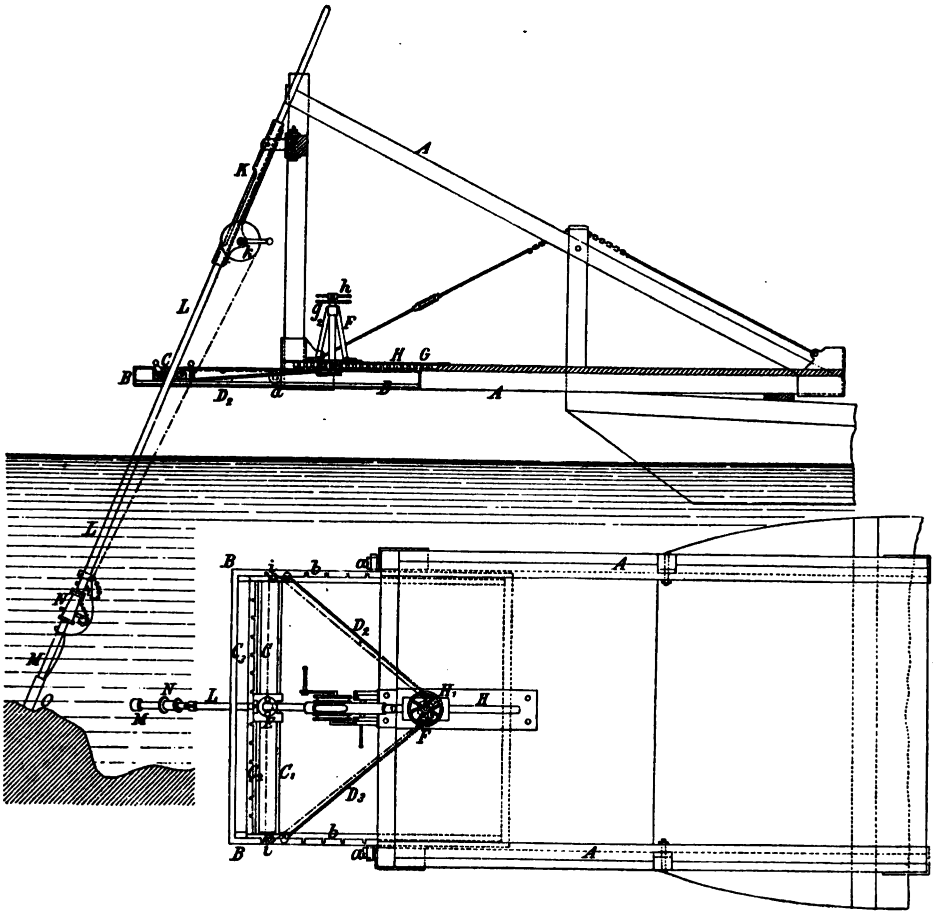


FIG. 144.

For rivers of over 10 feet depth the method devised by General John Lauer is very convenient.

A barge (Figs. 145 and 146) is fitted with an overhanging scaffold frame, *A*, carrying by two trunnion-bearings, *a*, the frame, *B*, which is made of channel iron, in which the carrier, *C*, runs (on balls, *d*); the latter can be clamped by aid of the notches. It carries a carriage, *E*, which can be traversed along the bars, C_1 C_2. A guide tube, *L*, carried by the pivoted hollow arm, *K*, and passing through *E*, can be pointed to any spot, within a certain range on the bed of the river. The tube can be set in any required direction by the windlass, *F*. At the lower end of *L* is a socket into



FIGS. 145 and 146.

which a wooden pole, *M*, carrying the blasting charge, is put. Soundings can also be taken by this apparatus, both before and after blasting. By using two such apparatus fixed to one barge, with charges of from 9 to

18 ounces, Colonel Lauer was able to blast from the bed of the Danube, near Peterwardein, at depths up to 38 feet, $173\frac{3}{4}$ cubic feet of rock daily. The object of the operation was to lower the river bed, and in some places a deepening of 6 feet 10 inches was effected; the cost was about one shilling and fivepence per cubic foot.

In the removal of the rapids known as the Danube Struden, the following arrangement was used by Mr. A. Schlepitzka. A framework, resembling a gigantic jib-crane, was erected on the bank. The jib consisted of a framed wrought-iron girder 130 feet long, which could be rotated round the central post, to which one end of it was attached; the other end was carried by a steel rope passing over a pulley on the top of a central mast down to a windlass, so that the jib-girder could be moved both horizontally and vertically about a centre formed by the end secured to the centre post. On the jib was a sliding carriage, carrying a diamond drilling apparatus. The drill-bar consisted of steel tubes successively screwed on as the hole advanced; the drill-point was, as usual, a cast-steel ring with a series of cutting points made of black diamonds (or bort) inserted into it. This bar was rotated through a suitable gearing by an electro-motor, and made from 1500 to 2000 revolutions per minute, the débris being forced out of the hole by a stream of water pumped through the steel tubes forming the boring-bar; the advancing of the drill was done by hand, and the number of the revolutions controlled by switching incandescent lamps in or out of the motor circuit, thus varying the current and, consequently, the speed of the motor.

Another method was used with great success on the removal of the "Iron Gate" of the Danube, and is due to Messrs. Lobnitz & Co. of Renfrew. It consists of a chisel cutter of steel, weighing between 10 and 15 tons, and fitted with a hard cutting point, which is allowed to fall from a height of 6 to 10 feet by its own weight on to the surface of the rock. The cutter is hoisted by a winch, released automatically after attaining the requisite height; and when it has fallen, the wire rope carrying it follows and raises it again by means of a clutch and automatic gear. The work is generally carried out in steps of about 3 feet in thickness. The cutter breaks about 2 cubic feet of rock per blow, and on an average 150 blows per hour are delivered.

It is sometimes necessary to remove large masses of *floating ice* that have jammed together in rivers. Holes are bored through the ice with bars which are made thickest at the cutting end, so as to prevent them freezing tight in the hole. Charges of about 2 lbs. of dynamite are sunk into them, or, if dynamite cannot be procured, 4-lb. powder charges may be used. The above charges may have to be increased for larger masses of ice. If a river is covered with ice for a great distance, the sides are first freed (working up stream) by larger charges of dynamite placed under the ice, which is broken and cracked, the blocks set free being carried down by the current.

INDEX.

PRINTED BY NEILL AND CO., LTD., EDINBURGH.