215 yards. The length and depth of this adit are not remarkable; but the great quantity of water discharged is a point of considerable interest and importance. It is estimated that this adit is now discharging 15 million gallons or 66,000 tons of water in twenty-four hours, although the outflow is purely natural, for no mines are pumping water into it. It is now easy to understand that the Rhosesmor mine, though provided with powerful pumping machinery, was unable to cope with the springs it encountered.

In the United States the famous Sutro tunnel is an adit of which the main branch, 4 miles in length, reaches the great Comstock lode in Nevada at a depth of 1700 feet. The total cost of this tunnel, which was completed in nine years, is estimated to have been $7,000,000. The quantity of water running out daily in 1879 was 12,000 tons, at a temperature of 123° Fahr. at the mouth of the tunnel. All this water must otherwise have been pumped to the surface at a cost estimated at $3000 a day. The obstacles to progress were very great: not only was the heat extreme, but swelling ground was encountered which snapped the strongest timber. Thanks, however, to the untiring energy of Mr Adolph Sutro, the difficulties were at last successfully overcome, and this great work will long remain as a monument to his foresight, skill, and patient pertinacity.

The Atlantic-Pacific tunnel,[1] which was commenced in 1880, will pierce the heart of the Rocky Mountains under Grey's Peak, Colorado. It is being driven from both sides of the watershed, and will have a total length of 4¾ miles from end to end.

Siphons have been used for unwatering workings in special cases; but of course they will not act unless the barrier over which the water is raised is very decidedly less than 33 feet.

Winding machinery. When workings cannot be drained by tunnels or siphons it is necessary to raise the water mechanically, either to the surface or at all events to an adit through which it can flow away naturally. If the amount of water is not too considerable, it is often convenient to use the winding machinery and draw up the water in special buckets (*water-barrels*) or tanks. The bucket may be tilted over on reaching the surface, or it may be emptied by a valve at the bottom. This means of raising water is often adopted while sinking shafts, when it may be desirable to wait till the whole or a portion of the shaft is completed before putting in the final pumping machinery.

Pumps. The varieties of pumps used in mines are numerous. In small sinkings hand-pumps, either direct-acting or rotary, may be applied; steam-jet pumps on the principle of the Giffard injectors are also used; and pulsometers, though requiring a large expenditure of steam, have the advantages of being quickly fixed, of occupying little space, and of working with sandy or muddy water. They are capable, therefore, of rendering great services in special cases. When we come to the definitive machinery erected in large mines of considerable depth, we find that the prevailing types of pumps are few. They may be classified as follows:—(A) lifting and force pumps worked by rods in the shaft actuated by wind, water, or steam power; (B) force-pumps at the bottom of the shaft worked by steam, compressed air, or hydraulic pressure.

A. In describing the first method we have to consider the motive power, the rods, and the actual pumps themselves.

Windmills have the disadvantage, which is often fatal, that the power is not constant. By erecting an auxiliary steam-engine, which can be set to work if wind fails, this evil is overcome; and at the Mona mines in Anglesea a windmill pumps up water from a depth of 80 fathoms at the rate of upwards of 90 gallons per minute. As the site of the mine is breezy, there is wind enough to work the mill about one-half of the time.

Water-power was for a long period the principal agent employed in draining mines, and it is still of the greatest utility in many districts, reservoirs being constructed to collect and store the rainfall. Some idea of the scale upon which these works are conducted will be gathered from the following figures relating to the Harz mines. In 1868 there were "sixty-seven reservoirs covering an area of 604 acres, and having a storage capacity of 336,000,000 cubic feet."[2] The total length of the various leats, races, and other water-courses, including the six principal adits, is about 170 statute miles. The net power extracted is reckoned at 1870 horse-power, but less than one-fourth of this is used for pumping.

Water-power is applied to pumping machinery by water-wheels, turbines, and rotary or non-rotary water-pressure engines. Excepting the case of the latter, the rotary motion has to be converted into a reciprocating motion by a crank; and furthermore with turbines the speed must be reduced very considerably by intermediate gearing.

Overshot wheels are the commonest prime movers when pumps are worked by water-power; water-wheels are frequently constructed 40 or 50 feet in diameter, and at the Great Laxey mine, in the Isle of Man, one of the wheels is no less than 72 feet 6 inches in diameter and 6 feet in the breast. The power is conveyed from the water-wheel by a connecting rod to a bell-crank (*bob*) placed over the shaft; and when, owing to the contour of the ground, the wheel has to be placed at a distance, it is connected to the bob by the so-called *flat rods*, made of wood, bars of iron, or wire-rope, travelling backwards and forwards, and supported by pulleys or oscillating upright beams.

Water-pressure engines have the advantage of being able at once to utilize any amount of fall, and those which are direct-acting can be applied immediately to the main rod of the pumps.

Steam, however, is the power used *par excellence* in draining mines; indeed the first applications of steam-power were made for this purpose, and Watt's great inventions owed their birth to the necessities of mines which could no longer be drained by the water-power at their command.

Cornish engine. The principal type of engine is that known as the Cornish engine, which is a single-acting condensing beam engine working expansively. Its mode of action may be briefly described as follows. The steam is let in at the top of the cylinder and presses down the piston, which is connected with one end of a large beam, whilst the main rod of the pumps is attached to the other. When the piston has completed its course the equilibrium valve is opened by a cataract, and, the pressure on both sides of the piston being now equal the weight of the pump rods, or rather the excess of their weight over that of the counterbalances, causes them to drop and force up the water from the mine by means of the plungers, which will be described immediately. Double-acting rotary engines working the pumps by cranks may also be met with.

The rod in the shaft, known as the *main rod* or *spear rod*, is usually made of strong balks of timber butted together and connected by *strapping plates* fastened by bolts. It serves to work either lifting-pumps or force-pumps, or both.

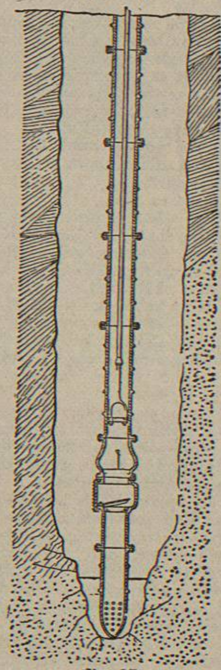

Fig. 87.

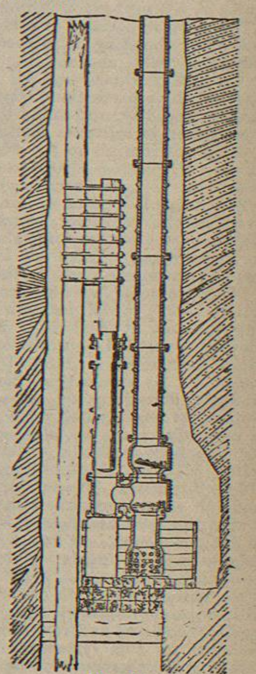

Fig. 88.

The lifting-pump, or drawing lift (fig. 87),[3] consists of the wind bore, the clack-piece, the clack-seat piece, the working barre

[1] *Mining and Scientific Press*, San Francisco, 1882, vol. xlv. p. 241.

[2] "Notes on the new Deep Adit in the Upper Harz Mines," by H. Bauerman, *Report of the Miners' Association of Cornwall and Devonshire*, 1868, p. 21.

[3] Michell and Letcher on "Cornish Mine Drainage." *Forty Third Annual Report of the Royal Cornwall Polytechnic Society*, p. [illegible].

surmounted by pumps, and the bucket with its rod. The whole works like any ordinary pump, and needs no special explanation.

The force pump used in mines, known as the plunger-pump, consists of a solid piston (*plunger*) (fig. 88)[1] working through a stuffing-box in a pump standing on the H-piece. This has a valve which communicates with the *windbore* resting in the cistern. Above the H-piece comes the *door-piece* with another valve, and then a series of pipes, generally of cast iron, but occasionally of wrought iron, constituting the column. The upward motion of the plunger, which is attached to the main rod, causes an inflow of water, which is forced into the column when the plunger descends. It is usual to fix a drawing lift at the bottom of the shaft, which raises the water into a first cistern, and thence a plunger forces it into a second cistern some 60 yards higher up; and it is continually forced up from cistern to cistern until it reaches the adit or the surface.

There are numerous important matters which require special attention, such as the valves, catches, balance-bobs, guiding arrangements for the rod in inclined shafts, the V-bobs, fend-off bobs, and running loops, which have to be used when there are bends in the shaft; but space will not permit of more than mere mention of these details.

Such then is the standard arrangement worked by steam or water power for pumping from mines. The great advantage of the system consists in the employment of the plunger, because it is simply necessary for the machine to raise a weight slightly greater than that of the water, which is forced up afterwards by the downstroke of the rods. Leaks are readily discovered, and the stuffing-box can be easily screwed up as the packing wears; this is one great reason of the superiority of the plunger compared with a piston working in a barrel.

The modifications of this system relate more to the engines employed than to the actual pumps themselves.

The cylinder of the Cornish engine is sometimes reversed and stands over the shaft, the main rod being attached directly to the piston. This type of engine, known as the Bull engine in Cornwall, dispenses with the ponderous beam, but it has the great disadvantage of obstructing the mouth of the shaft. The use of two cylinders combined, as invented by Woolf, causes less strain upon the main rod and pumps (*pit-work*) and machinery generally, as the initial velocity of the piston is smaller and the engine starts with less jerk. The cylinders are placed side by side or one above the other.

Kley's engines. Kley, of Bonn, has constructed engines on the Woolf system with steam acting on both sides of the pistons. He makes the excess of the weight of the rod over that of the counterbalances sufficient to raise only half the weight of the water and to overcome the friction; and then in the descending stroke the steam acts on the top of the piston and so makes up for the insufficiency in force of the rods. As the steam acts on both sides of the piston the same amount is consumed, it is true, but a smaller cylinder will do the work, and the original cost of the engine is lessened. The same engineer of late years has put up several pumping engines in Belgium, Germany, and France of 30 to 560 horse-power, with a fly-wheel which serves simply to regulate the stroke of the piston, so that the crank always stops before or after the dead point till the cataract starts another stroke. The engines are double-acting, with two cylinders and beam. The advantage of working with the fly-wheel is that the main rod and pumps are set in motion without the injurious jerk unavoidable with a Cornish engine worked at a high rate of expansion.

Guinotte's engine. M. Guinotte, the well-known Belgian engineer, also adopts a fly-wheel, and the engines he has erected at Mariemont and elsewhere are single-acting rotary engines with one cylinder. The peculiarity of the fly-wheel is that he can weight it in any way he pleases; and he so overcomes the difficulty, which occurs in other rotary machines, of its being impossible to work them below a certain speed. His object has been to make the speed slow at the beginning and end of a stroke, so as to avoid the injurious shocks to the valves and machinery generally from sudden starts and stoppages. In order to make the main rod act by traction only and not compression, which may be advisable with iron rods, the plungers are sometimes reversed; whilst Kraft of Seraing has introduced the Rittinger pump, which consists of a hollow moving plunger with a valve inside, and a plunger case above it working over a hollow fixed plunger. By this arrangement both the up and the down stroke of the engine cause water to be forced up; and this pump is used with a double-acting rotary engine.

B. We must now speak of the second class of pumps, viz., force-pumps worked by steam, water-power, or compressed air at the bottom of the shaft.

The steam pumps are of very various descriptions,[2] but they mostly consist of one or two plungers, or rams, set in motion by a rotary or a non-rotary engine, which may or may not work with expansion and condensation. The plunger or ram is generally fixed directly on to the piston, and works in the same line, consequently the power is transmitted to the plunger with the least possible loss. The water is forced up the shaft in one long column. Engines and pumps of this kind are easily kept in order; all the parts are readily accessible. The miner is able to dispense with the heavy beam, the massive engine-house, the long main rod and its connexions and bobs, the various cisterns and plungers, and instead he has a compact and easily supervised machine and a simple line of pipes taking up but little space in the shaft; the pump can therefore be erected and set to work very quickly, and this is a matter of the utmost importance in emergencies. It is true that these direct-acting steam-pumps, even when worked by a compound engine, cause a greater consumption of coal than the Cornish engine; but, as a set off, there is the economy in first cost, erection, and repairs which has led to their adoption more especially in collieries. The steam is generated by boilers underground, or is conveyed from the surface in well-jacketed pipes.

If natural water-power is available water-pressure engines working the plunger directly are often employed, and indeed such water-power may be created artificially for use in workings where steam-power is objectionable on account of the heat. There are other reasons too for employing water for transmitting power; where the length of the rods is very great, and they have to be worked quickly, there is a great liability to breakages; in order to overcome these difficulties at the mines on the Comstock lode, Mr Joseph Moore[3] uses a steam-engine at the surface to work an hydraulic accumulator, and then by pipes conveys the water under pressure to hydraulic engines working plungers. These are fixed at 2400 feet from the surface, and force the water in one column, 813 feet high, to the level of the Sutro tunnel. The exhaust water is returned to the surface in pipes and used over again. The pumps are now raising 1600 to 1700 gallons per minute.

Where compressed air is being supplied to a mine for drilling and winding purposes, it is often convenient to employ it, by means of direct-acting pumps, such as are generally used with steam, for the drainage of small temporary sinkings; and occasionally large pumps raising considerable quantities of water are worked in this way.

11. *Ventilation and Lighting.*—The composition of the air of the atmosphere is about one-fifth by volume of oxygen and four-fifths of nitrogen, with a little carbonic acid gas; more exactly, the standard amount of oxygen may be taken at 20·9 per cent., and that of the carbonic acid gas at 0·03 per cent. The atmosphere of mines is subject to various deteriorating influences: not only do noxious gases escape from the rocks into the underground excavations, but also the very agents employed in the execution of the work itself pollute the air considerably.

The dangerous emanations of fire-damp in collieries have been already described (COAL, vol. vi. p. 72); and with reference to this gas it is simply necessary to say that its presence is not entirely confined to coal mines. Large quantities have been observed in Silver Islet mine,[4] Lake Superior, where several explosions have occurred, whilst small quantities are met with in the stratified ironstone of Cleveland, and also in the Cheshire salt mines; jets of the gas may be seen constantly burning in the salt mine at Bex in Switzerland; a little has been noticed also in lead mines in Wales and Derbyshire. In the Sicilian mines the amount given off by the black carbonaceous shales interstratified with the sulphur beds is sufficient to cause dangerous explosions. It has been pointed out (vol. vi. p. 72) that carbonic acid gas exudes from coal;[5] it escapes also from some mineral veins. At the lead mines of Pontgibaud in central France it is so abundant that special fans have to be provided for getting rid of it; very distinct issues of this gas may be observed at the Foxdale mines in the Isle of Man, and in the Alston Moor district it is not

[1] Michell and Letcher on "Cornish Mine Drainage," *Forty-Third Annual Report of the Royal Cornwall Polytechnic Society*, p. 211.

[2] Stephen Michell, *Mine Drainage*, London, 1881.

[3] *Trans. Inst. Engineers and Shipbuilders in Scotland*, 1882.

[4] *Engineering and Mining Journal*, vol. xxxiv. p. 322.

[5] A. Schondorff, "Untersuchung der ausziehenden Wetterströme in den Steinkohlenbergwerken des Saarbeckens," *Zeitschrift für das Berg-, Hütten-, und Salinen-Wesen im Preussischen Staate*, vol. xxiv. p. 73; and Cl. Winkler, "Die chemische Untersuchung der bei verschiedenen Steinkohlengruben Sachsens ausziehenden Wetterströme und ihre Ergebnisse," *Jahrbuch für das Berg- und Hüttenwesen im Königreiche Sachsen auf das Jahr* 1882, p. 65.

uncommon. This gas is likewise given off in the Sicilian sulphur mines, where also the highly poisoncus sulphuretted hydrogen is of frequent occurrence, the water in the workings being often saturated with it. Small quantities of mercurial vapour occur in quicksilver mines.

Such then are the principal gases which naturally pollute the atmosphere of mines, and have to be swept out by ventilation. In addition to these we have the products of the respiration of the men and animals in the pit, and those due to the combustion of candles or lamps, and the explosion of gunpowder, dynamite, &c.

Dr Angus Smith[1] reckons that two men working eight hours, and using ½ lb of candles and 12 oz. of gunpowder, produce 25·392 cubic feet of carbonic acid (anhydride) at 70° F.,—viz., 10·32 by breathing, 12·276 by candles, and 2·796 by gunpowder.

The products of the explosion of gunpowder have been carefully studied by Captain Noble and Sir Frederick Abel, and the following figures, showing proportions by weight, are copied from the valuable paper[2] containing the results of some of their researches:—

	Curtis & Harvey's No. 6 Gunpowder.	Mining Powder.
Total solid products	57·74	47·04
Total gaseous products	41·09	51·35
Water	1·17	1·61
	100·00	100·00

The solid residue of the mining powder consisted mainly of potassium carbonate, potassium monosulphide, and sulphur. The percentage-composition by volume of the gas produced was:—

	Curtis & Harvey, No. 6.	Mining Powder.
Carbonic anhydride	50·22	32·15
Carbonic oxide	7·52	33·75
Nitrogen	34·46	19·03
Sulphuretted hydrogen	2·08	7·10
Marsh gas	2·46	2·73
Hydrogen	3·26	5·24
	100·00	100·00

The volume (calculated for a temperature of 0° C. and barometer 760 mm. of mercury) of permanent gases generated by the explosion of 1 gramme of dry powder is—

Curtis & Harvey, No. 6 .... 241·0 cubic centimetres.
Mining .... 360·3 „ „

MM. Sarrau and Vieille have communicated to the Academy of Sciences[3] the results of their researches concerning the decomposition of certain explosives, and more particularly gun-cotton and nitrated gun-cotton. The following table shows, in litres, the volume (at 0° C. and 760 mm. of mercury) of each of the gases per kilogramme of the substance exploded in a closed vessel:—

Kind of Explosive.	CO.	CO_2.	H.	N.	O.	C_2H_4.	HS.	Total.
Pure gun-cotton	234	234	166	107	...	...	...	741
Gun-cotton and nitrate of potash (50 per cent. of each)	...	171	...	109	45	...	...	325
Gun-cotton (40 per cent.) and nitrate of ammonia (60 per cent.)	...	184	...	211	6	...	...	401
Nitro-glycerin	...	295	...	147	25	...	...	467
Ordinary blasting powder	64	150	4	65	...	4	17	304

If, however, the explosive is decomposed at a pressure approaching that of the atmosphere, the volumes (again at 0° C. and 760 mm. of mercury) are very different, as shown below:—

Kind of Explosive.	NO_2	CO.	CO_2.	H.	N.	C_2H_4	Total.
Pure gun-cotton	139	237	104	45	33	7	565
Gun-cotton and nitrate of potash (50 per cent. of each)	71	58	57	3	7	...	196
Gun-cotton (40 per cent.) and nitrate of ammonia (60 per cent.)	122	65	103	12	112	...	414
Nitro-glycerin	218	162	58	7	6	1	452

When explosives are decomposed in this way they liberate nitric oxide and carbonic oxide, and the analyses of MM. Sarrau and Vieille confirm the practical experience of miners, who complain greatly of noxious fumes when, owing perhaps to a bad detonator, a charge of dynamite or tonite fails to explode properly.

The air of mines is finally deteriorated by organic matter contained in the exhalations of the men and animals employed and in the products of decaying timber, by dust, and by the solid particles constituting the smoke of explosives. It must be recollected also that the injury to the air is not confined to the addition of the gases and substances just mentioned; but the proportion of oxygen is diminished by the combustion of candles, by respiration, the decay of timber, and decomposition of some minerals such as iron pyrites. Dr Angus Smith[4] sums up the results of his analyses of the air of British metal-mines as follows:—

	Percentage by volume.
Oxygen, average of 339 specimens	20·26
„ of ends	20·18
„ other parts	20·32
„ in currents	20·65
„ in large cavities	20·77
„ just under shafts	20·42
„ in sumps	20·14
Carbonic acid	0·785

He considers air with 20·9 per cent. oxygen as normal, and air with proportions between that and 20·6 as impure; and where the percentage of oxygen descends below 20·6 he calls the air exceedingly bad. According to these standards, only 10·67 per cent. of the samples showed the air to be normal or nearly so; 24·69 per cent. were decidedly impure; whilst 64·63 per cent. or nearly two-thirds of the samples were exceedingly bad. The amount of oxygen in one specimen was as low as 18·52 per cent., whilst the carbonic acid often exceeded 1 per cent. and in several instances 2 per cent. It is evident that twenty years ago the ventilation of British metal mines was anything but satisfactory, and even now there is room for improvement.

Having explained the reasons why the air of mines must be constantly renewed, we must now point out how this desirable end is effected.

Systems of ventilation

Two systems are employed,—natural ventilation and artificial ventilation; but, as both systems have been described (COAL, vol. vi. p. 70), little remains to be said here, especially as the ventilating machines in metalliferous mines generally cannot for one moment be compared with the powerful appliances employed in collieries. In vein-mining there are generally many more shafts than in collieries, and natural currents are set up which are often considered sufficient for ventilating the mines; nevertheless, the advanced workings, such as the ends, rises, and winzes,—in fact all workings in the form of a *cul-de-sac*,—are likely to require special means of ventilation as soon as they proceed a little distance from the main air-current.

The means of ventilating a drift or heading are various. If a natural or artificial draught exists at the mouth of the drift, it may be diverted by an upright partition (*brattice*), or an air-way may be constructed along the roof or floor by a horizontal partition of planks (*air-sollar*) (fig. 89). In this way a sufficient supply is secured at the end or fore-breast.

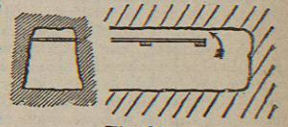
Fig. 89.

The water-blast is another simple appliance; it is precisely the same as the well-known tromp, and it blows a current of air through square pipes made of boards, or better through cylindrical pipes of sheet zinc. The fall of water may be applied by Williams's water-jet, shown in fig. 90. The jet of water acts like an injector, and creates a powerful current.

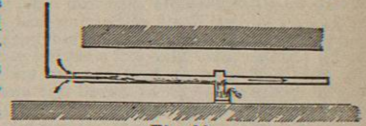
Fig. 90.

Small fans driven by boys, or better by small water-wheels or other machinery, are frequently applied, and the Harz blower (*duck machine*, Cornwall) (fig. 91) is not uncommon. This is merely an air-pump of very simple construction which is worked by the main rod of the pumps, and can be arranged so as to exhaust the foul air or force in fresh air.

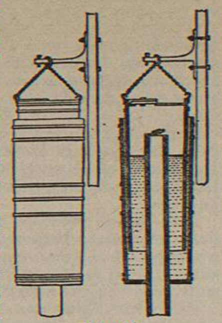
Fig. 91.

In working in blasting ground, boring-machines driven by compressed air are becoming more and more largely used every day, and the exhaust air escaping from the machines is invaluable for ventilation. At the same time, on account of volley firing, the quantities of deleterious gases generated in a short space of time are very considerable; and, in order to get rid of them speedily, the compressed air may be utilized for working a Körting aspirator or the somewhat similar ventilator of Mr Teague, a jet of compressed air turned into a ventilating pipe, which creates an exhaust (fig. 92[1]). Naturally this ventilator is merely brought into play at the time of blasting, and while the boring machinery is out of use. When compressed air is being supplied on a large scale to a mine for boring and winding machinery, it is often convenient to convey it by a small gas-pipe to working places in which the ventilation is inadequate. Of course, in one sense, it is very uneconomical to compress air to a pressure of 60 or 70 lb to the square inch for ventilating purposes only; but, where compressing machinery is always at work on the mine, it may be better to be a little wasteful of cheap power at the surface than to go to the greater expense of having a man or boy to work a fan underground.

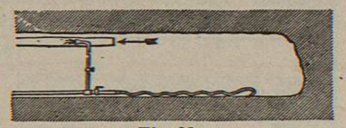
Fig. 92.

Lighting

Mines are lighted by lamps, torches, candles, and electricity. The subject of safety lamps for fiery mines has already been discussed (see COAL, vol. vi. p. 72), and consequently the question of illuminating mines may be treated in a very summary manner.

Lamps vary very much in shape and size. The Sicilian miner has a mere shallow cup of unglazed pottery; the Saxon a small tin or brass lamp in a wooden box lined with tinplate and open in front. In the Harz the miner prefers a heavy flat iron lamp with a hook by which it is stuck into the timber or any crack in the rocks; in France, northern Italy, and parts of Spain, the iron lamp is lenticular in shape and also suspended by a hook. In Scotland, and parts of Germany and the United States, a small tin lamp of the shape shown in fig. 93 is very common; the hook enables it to be carried on the hat while climbing ladders, and to be fixed up underground. Olive oil and rape oil are burnt in these lamps; petroleum lamps are employed occasionally.


Fig. 93.

The miners of England and Wales still cling to the tallow candle; and when surrounded by a lump of clay it can easily and quickly be fixed in the working place or carried upon the hat when climbing. Gas brought down from the surface answers for illuminating large excavations, such as on-setting places and engine-rooms.

Up to the present time the electric light has been but little used underground on account of its want of portability, and the smallness of the spaces requiring illumination. Very often a few men only are employed in each working place, and consequently the expense incurred in fixing and shifting the lamps and maintaining them alight would be out of proportion to the value of the work executed. However, an incandescent electric lamp has been invented weighing only 10 lb, which gives the light of three candles for six hours, and it may be reasonably expected that improvements will be made which will render the electric light more available for underground purposes than it is at present. When the area requiring illumination is large, an arc-lamp may be used with advantage.

Among the first successful applications of electric lighting to underground excavations may be mentioned that of M. Blavier at the Angers slate quarries.[2] In the year 1879 he fixed two Serrin lamps in one of the large underground chambers with an area of 2400 square yards, and he found that they gave light enough for all the men at work. The total cost, reckoning everything, viz., coal, carbons, repairs, labour, depreciation of plant, and interest on capital, is 50 francs per day; the gas formerly in use cost 54 francs a day and gave much less light. It is evident, however, that the arc lights can only be applied with advantage in special cases where a large number of men are concentrated in one working area which can be illuminated from one or two points.

The large chambers in the salt mine of Maros-Ujvár in Hungary have been regularly lighted up by electricity since 1880. The cost is somewhat greater than that of the tallow, oil, or petroleum formerly in use; but, on the other hand, the illumination is better, the men can do more work and are more easily supervised, whilst the air of the mine is not deteriorated by the products of combustion of the lamps.[3]

12. *Means of Descending into and Ascending from Mines.*—Where mines are worked by adit-levels the men naturally walk in along the ordinary roadways; such mines, however, are exceptional, and the men generally have to climb down and up by ladders, or are raised and lowered by machinery. The means of access to and from workings may be classified as follows:—(1) steps and slides; (2) ladders; (3) cages; (4) man-engines.

Steps.

If a lode or seam is inclined at an angle or 40° or 50° from the horizon, steps may be cut in the floors of the deposit if it is firm enough, or wooden stairs may be put in with a hand-rail. Even with higher dips steps may be arranged by directing them in a line intermediate between the dip and the strike. In speaking of conveyance underground, reference has already been made to the practice of carrying sulphur ore in Sicily and slate in Germany up to the surface by steps; and steps may be found in other foreign mines and occasionally in Great Britain. They are much less fatiguing than ladders placed so flat that part of the weight of the body rests upon the arms. In some of the Austrian salt mines the men descend by wooden slides inclined at angles varying from 30° to 50°, flattening at the bottom to destroy the velocity gradually; the ascent is effected by steps. Slides.

Ladders

Ladders are very largely used in metal mines all over the world, but they vary a good deal in different countries. The ladder consists of two sides and a series of rungs (*staves*, Cornwall). The sides are usually made of wood, and the rungs of wood or iron. The distance between the rungs is important; 10 inches from centre to centre is sufficient, for climbing upon ladders with the rungs 12 inches apart is decidedly more fatiguing. On the Continent wooden rungs are commoner than iron ones, and oak is preferred. Sometimes the wooden staves, instead of being round, are flat, so as to stand more wear, and iron sides may be seen in places where dry rot is very bad. Platforms should be fixed at short intervals, not exceeding 3 or 4 fathoms in perpendicular shafts, so as to prevent falls from having fatal consequences.

In many cases sufficient attention is not paid to the angle of inclination of the ladders. A ladder is climbed with the least fatigue when the person uses his arms simply to steady himself, and is not compelled to pull himself up by them, as on a vertical ladder, or to support much of the weight of his body by them, as happens with a very flat one. The best angle is about 20° from the vertical, and in Belgium the authorities have very wisely decreed that no ladder shall be inclined at an angle of less that 10° from the vertical. Furthermore, of the two arrangements shown in fig. 94

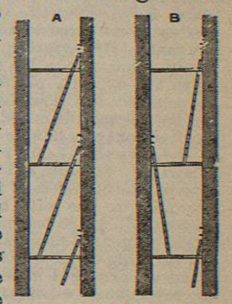

Fig. 94.

[1] *Report of the Commissioners Appointed to Inquire into the Condition of all Mines in Great Britain to which the Provisions of the Act 23 & 24 Vict. c. 151 do not apply*, Appendix B., p. 224.

[2] "On Fired Gunpowder," Captain Noble and Mr F. A. Abel, *Phil. Trans.*, 1880, p. 278.

[3] "Recherches expérimentales sur la décomposition de quelques explosifs en vase clos; composition des gaz formés," *Comptes Rendus*, 1880, pp. 1058 and 1112.

[4] *Op. cit.*, p. 222.

[1] *Trans. Roy. Geol. Soc. Cornwall*, vol. x. p. 142.

[2] M. Blavier, "L'Éclairage électrique aux Ardoisières d'Angers, *Annales des Mines*, ser. 7, vol. xvii., 1880, p. 5.

[3] *Oesterreichische Zeitschrift für Berg- und Hüttenwesen*, 1882, No. 25, p. 296.

A is better than B, because it not only affords a greater inclination for the ladders, but also renders it less likely that a man will drop through the opening (*manhole*) in the platform (*sollar*) if he loses his hold and falls. These may seem trifling matters; but, leaving aside the question of safety, the economy derived from fixing the ladders at the best inclination is by no means small. To make this apparent we must recollect the depths to and from which men have to climb, viz., 300, 400, and even 500 yards. It is important, therefore, to save every unnecessary expenditure of energy, which, though trifling for one ladder, becomes considerable when repeated a great number of times. When a mine has reached a depth of 200 yards, and *a fortiori* when it exceeds it, mechanical appliances should be introduced for raising and lowering the men, because time and strength are wasted by climbing. Medical men also are agreed that excessive ladder-climbing is injurious to the health of the miner. Therefore, both upon hygienic and financial grounds, one of the first thoughts in working a mine should be the conveyance of the men up and down the shafts by machinery with the least possible fatigue.

Cages. In collieries and other mines worked by perpendicular shafts, it has long been customary to raise and lower the men by the ordinary winding machinery already described. In the United Kingdom it is necessary that guides should be used if the shaft exceeds 50 yards in depth; safety-catches and disengaging hooks (COAL, vol. vi. p. 75) are frequently applied for the purpose of preventing accidents. The simplicity of this method of ingress and egress naturally renders it popular, and statistics prove that, where proper precautions are used, it is exceedingly safe.

Man-engines. The first man-engine was put up in the Harz in 1833, and nine years later a similar machine was fixed in Tresavean mine in Cornwall. Since that time this very useful means of conveying workmen up and down shafts has been resorted to in other mining districts, and especially in Belgium and Westphalia.

Two kinds of man-engine are in use, the double-rod machine and the single-rod machine. The double-rod or original man-engine consists of two reciprocating rods like the main rods of pumps, carrying small platforms upon which the men stand. The stroke is from 4 to 16 feet, and the little platforms are so arranged that they are always opposite each other at the beginning and end of each stroke.

Figs. 95 and 96 represent the rods in the two final positions. A man who wishes to descend steps upon platform *b* (fig. 95); the rod B goes down, and A goes up, so that *b* (fig. 96) is brought opposite *c*. The man steps across from *b* to *c*, and then the rod A makes a down-stroke, B an up-stroke. Platform *c* is now opposite *d* (fig. 95), and the man again steps across; and thus, by constantly stepping from the rod as it completes its down-stroke, the man is gradually conveyed to the bottom of the shaft. By reversing the process, or, in other words, by stepping off on to the opposite platform as soon as the rod has completed its up-stroke, the man is raised to the surface, without any fatigue beyond that of the very slight effort of stepping sideways. If each rod makes four up and down strokes of 10 feet each per minute, the rate of ascent or descent will be 80 feet per minute.

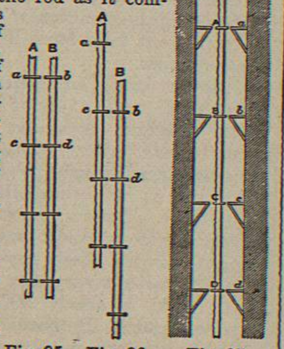

Fig. 95. Fig. 96. Fig. 97.

The single-rod man-engine has one rod carrying steps, whilst fixed platforms are arranged in the shaft so as to correspond exactly with them (fig. 97). If a man wants to go down, he steps on to A when the up-stroke is completed; the rod goes down and A is brought down opposite to the fixed platform *b*, on to which he steps off. He then waits on *b* until the rod has finished its up-stroke. B is brought opposite *b*; he steps on to B, the rod goes down and he is brought opposite *c*, where he steps off again and waits. By reversing the operation he is gradually lifted to the top of the shaft. The single-rod engine may be used by men going up while others are going down, provided that there is sufficient room upon the fixed platforms (*sollars*). The best plan is to have sollars right and left, as shown in the figure, and then the ascending men step off to the left, for instance, while the descending men take the right-hand sollars. The ascending man steps on to the man-engine as soon as the descending man steps off, and so the rod may be always carrying men up or down. The usual stroke in Cornwall is 12 feet, and there are from three to five or six strokes a minute. With five strokes the men descend 10 fathoms a minute, or in other words a descent or ascent of 300 fathoms occupies half an hour. The reciprocating motion is best obtained from a crank, because in this case the speed is diminished gradually at the dead points, and the danger of an accident in stepping off and on is thereby diminished; man-engines, however, are sometimes driven by direct-acting engines.

Man-engine rods are constructed of wood or iron; and at Andreasberg in the Harz each rod is replaced by two wire ropes. Like a pump rod the man-engine rod requires proper balance bobs and catches, and for the safety of the men a handle is provided at a convenient height above each step.

The man-engine has one great advantage over the cage, which consists in the fact that it can be safely applied in inclined and even crooked shafts; and it is for this reason that man-engines have been adopted in many metal mines unprovided with vertical shafts.

Careful comparisons as regards safety of travelling have been made in Prussia between ladders, man-engines, and cages. The average accidental death-rate is shown by the accompanying table, which gives averages for a period of ten years, 1871 to 1880:—

	Ladders.	Man-engines.	Cages.
Average annual number of men travelling.	73,942	7,191	64,071
Total number of persons killed............	75	41	74
Average annual death-rate per 1000.........	0·101	0·570	0·115

The table shows that the cage is nearly as safe as ladders. In reality, if the actual distance travelled were taken into account, the cage would appear to be safer, because we may fairly assume that the mines in which men are hoisted by cages are on the whole very much deeper than those in which men ascend and descend by ladders. The man-engine appears to be decidedly more dangerous than either the cage or ladders. Here again a distinction requires to be made between the single-rod and the double-rod machines, and the Prussian statistics include many of the latter. It will be readily understood that a fall in a naked shaft with few fixed platforms is much more likely to be fatal than a fall in the shaft of a single-rod man-engine which is closed with the exception of the manhole at intervals of 12 feet. The Belgian *warocquères* are rendered safer than the Harz or Saxon man-engines by having a railing round the back of each platform on the rod. Some of the double-rod machines are made with large platforms so that two persons can stand on them, one going up and the other going down, or both travelling in the same direction. The use of double-rod man-engines has been entirely abandoned in the United Kingdom. The death-rate from accidents on man-engines in Cornwall and Devon during the nine years 1873 to 1881 was 0·17 per 1000 persons using them, whilst the annual death-rate per 1000 persons using ladders was slightly higher, viz., 0·19. If the actual distance travelled were taken into account, the scale would turn more decidedly in favour of the man-engine.

The cost of raising and lowering men by the man-engine is not great. At Dolcoath, a tin mine in Cornwall approaching 400 fathoms in depth (see figs. 62, 63), it is reckoned that 1½d. per man per day covers all expenses, including interest upon the capital expended and depreciation of plant.

13. *Dressing or Mechanical Preparation of Ores.*—In a large number of cases the mineral, as it is raised from the mine, is not ready for sale. It usually requires to be subjected to mechanical processes whereby the good ore is entirely or partly freed from valueless veinstone. These processes, which in a few special instances are aided by calcination in furnaces, are known as the dressing or mechanical preparation of the ores. As a rule the valuable ore is specifically heavier than the veinstone, and most of the separating processes are based upon the fact that the heavy particles of ore will fall in water more quickly than the light particles of veinstone.

The processes of mechanical preparation may be classified as follows:—(1) washing and hand-sorting; (2) disintegration, or reduction in size; (3) classification by size or by equivalence; (4) concentration.

(1) Sometimes the ore coming from the mine requires simply to be freed from adhering particles of clay in order

to be rendered fit for sale, at other times the washing is necessary as a preliminary process previous to sorting by hand. The operation is performed either by raking the ore backwards and forwards upon a grating under a stream of water, or in a box containing water, or, thirdly, by means of an inclined revolving iron drum worked by hand or any other motive power. The machines used for this purpose, known as washing trommels, are revolving cylinders or truncated cones of sheet-iron provided with teeth inside. The ore is fed in at one end, is subjected to the action of a stream of water, and is discharged at the other end.

The *stuff*, *i.e.*, the mixed ore, veinstone, and country rock, having been cleansed, it is now possible to make a separation by hand. Women and children are generally employed for this work, as their labour is cheaper and their sight sharper than that of men. The stuff is spread out on a table, and various classes are picked out according to the nature of the products furnished by the mine. Thus in a lead mine we may have—(*a*) clean galena, (*b*) mixed ore, *i.e.*, pieces consisting partly of galena and partly of barren veinstone, (*c*) barren veinstone and country rock. This is a most simple case; very frequently we have to deal with a vein producing ores of two metals, especially in the case of lead and zinc, and then the classification into various qualities becomes more complicated.

Disintegration. (2) Reduction in size is necessary for two reasons. Even when an ore is sufficiently clean for the smelter, the large lumps are often crushed by the miner for the sake of obtaining a fair sample of the whole, or supplying a product which is at once fit for the furnace. The chief reason, however, for disintegration lies in the fact that the particles of ore are generally found enclosed in or adhering to particles of barren veinstone.

The disintegration is effected by hand or by machinery. Large blocks of ore and veinstone are broken by men with large sledge hammers, and the reduction in size is continued very often by women with smaller hammers. Sometimes the blow of the hammer is directed so as to separate the good from the poorer parts, and hand-picking accompanies this process, called *cobbing*. Ore may be crushed fine by a flat-headed hammer (*bucking iron*) on an iron plate.

The machines used for reducing ores to smaller sizes are very numerous; here it is impossible to do more than briefly call attention to those most commonly used. These are stone-breakers, stamps, rolls, mills, and centrifugal pulverizers.

The stone-breaker, or rock-breaker, is a machine with two jaws, one of which is made to approach the other, and

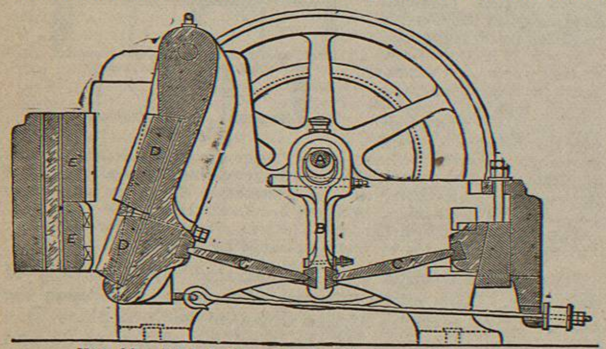

FIG. 98.—Blake's Stonebreaker, improved by Marsden.

so crack any stone which lies between them. The best-known stone-breaker is the machine invented by Blake, which has rendered inestimable services to the miner for the last twenty years, and the introduction of which constituted a most important step in advance in the art of ore-dressing. Its mode of action is very simple. When the shaft A (fig. 98) revolves, an excentric raises the "pitman" B, and this, by means of the toggle-plates C, C, causes the movable jaw D to approach the fixed jaw E by about $\frac{3}{8}$ inch at the bottom. When the pitman descends the jaw is drawn back by an india-rubber spring. The jaws are usually fluted, the ridges of one jaw being opposite the grooves of the other, and they are so constructed that the wearing parts are quickly and easily replaced.

Mr Marsden of Leeds has lately introduced a pulverizer, constructed on the principle of the stone-breaker, which will reduce large stones to the finest powder in one operation. The moving jaw has an up-and-down as well as the old backwards-and-forwards motion, and the stones are first cracked and then ground by the double action.

Stamps. Stamps are pestles and mortars worked by machinery. The construction of the modern California stamp mill with revolving heads is explained in GOLD, vol. x. p. 747, and the description need not be repeated. In Cornwall the older form with rectangular heads still prevails.

It is impossible to give any correct average figures representing the work done by a stamping mill, because this varies with the hardness of the stuff treated and the fineness to which it must be reduced. However, it is usual in Cornwall to reckon 1 ton of tinstuff and in California 1 to 1¼ ton of gold quartz stamped per horse-power in twenty-four hours.

Stamps are principally used in dressing the ores of gold, silver, and tin, but are occasionally employed for those of copper and lead. The stamps described at vol. x. p. 747 act simply by gravity. Another form, which has met with favour in the Lake Superior district, is the direct-acting or Ball stamp, which works like a steam hammer, the blow of the head being assisted by the pressure of steam. At the Calumet and Hecla Mill, Lake Superior, each Ball stamp is capable of crushing 130 tons in twenty-four hours. In a third kind of stamps, the heads are lifted by a crank and the power of the up-stroke compresses a cushion of air (pneumatic stamps) or a spring, storing up power which makes the down-stroke strike a heavier blow.

Rolls. Revolving rolls were introduced in the west of England in the early part of the present century to replace *bucking* by hand. The machine, now often known as the Cornish crusher, consists of two cast-iron or steel cylinders which revolve towards each other, whilst at the same time they are kept pressed together by levers or springs. The cylinders or rolls are generally from 18 inches to 2 feet or 2 feet 8 inches in diameter and 12 to 22 inches wide.

Stone mills constructed like flour mills are employed in some countries for reducing ores to powder; and the *arrastra*, which consists of heavy stones dragged round upon a stone bed, has rendered good service in grinding and amalgamating gold and silver ores, in spite of its being slow and cumbersome. Edge-runners (Chilian mills) also deserve mention.

Iron mills, known as *pans*, with grinding surfaces made of chilled cast-iron and arranged so that they can be quickly and easily replaced when worn out, are greatly in vogue in the United States for the treatment of ores of gold and silver; the ore delivered to them is already finely divided, and they are intended, not only still further to reduce the size of the particles, but also and more especially to effect the amalgamation of the precious metals with quicksilver. The pulverizers used in Cornwall for grinding grains of tin ore with a little waste still adhering to them are also iron mills.

The centrifugal pulverizers are machines by which the