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A SERIES OF TEXTBOOKS FOR PERSONS ENGAGED IN THE ENGINEERING PROFESSIONS AND TRADES OR FOR THOSE WHO DESIRE INFORMATION CONCERNING THEM. FULLY ILLUSTRATED AND CONTAINING NUMEROUS PRACTICAL EXAMPLES AND THEIR SOLUTIONS

ROCK BORING
ROCK DRILLING
EXPLOSIVES AND BLASTING
COAL-CUTTING MACHINERY
TIMBERING
TIMBER TREES
TRACKWORK

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86

86

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PREFACE

The International Library of Technology is the outgrowth of a large and increasing demand that has arisen for the Reference Libraries of the International Correspondence Schools on the part of those who are not students of the Schools. As the volumes composing this Library are all printed from the same plates used in printing the Reference Libraries above mentioned, a few words are necessary regarding the scope and purpose of the instruction imparted to the students of—and the class of students taught by—these Schools, in order to afford a clear understanding of their salient and unique features.

The only requirement for admission to any of the courses offered by the International Correspondence Schools, is that the applicant shall be able to read the English language and to write it sufficiently well to make his written answers to the questions asked him intelligible. Each course is complete in itself, and no textbooks are required other than those prepared by the Schools for the particular course selected. The students themselves are from every class, trade, and profession and from every country; they are, almost without exception, busily engaged in some vocation, and can spare but little time for study, and that usually outside of their regular working hours. The information desired is such as can be immediately applied in practice, so that the student may be enabled to exchange his present vocation for a more congenial one, or to rise to a higher level in the one he now pursues. Furthermore, he wishes to obtain a good working knowledge of the subjects treated in the shortest time and in the most direct manner possible.

In meeting these requirements, we have produced a set of books that in many respects, and particularly in the general plan followed, are absolutely unique. In the majority of subjects treated the knowledge of mathematics required is limited to the simplest principles of arithmetic and mensuration, and in no case is any greater knowledge of mathematics needed than the simplest elementary principles of algebra, geometry, and trigonometry, with a thorough, practical acquaintance with the use of the logarithmic table. To effect this result, derivations of rules and formulas are omitted, but thorough and complete instructions are given regarding how, when, and under what circumstances any particular rule, formula, or process should be applied; and whenever possible one or more examples, such as would be likely to arise in actual practice—together with their solutions—are given to illustrate and explain its application.

In preparing these textbooks, it has been our constant endeavor to view the matter from the student's standpoint, and to try and anticipate everything that would cause him trouble. The utmost pains have been taken to avoid and correct any and all ambiguous expressions—both those due to faulty rhetoric and those due to insufficiency of statement or explanation. As the best way to make a statement, explanation, or description clear is to give a picture or a diagram in connection with it, illustrations have been used almost without limit. The illustrations have in all cases been adapted to the requirements of the text, and projections and sections or outline, partially shaded, or full-shaded perspectives have been used, according to which will best produce the desired results. Half-tones have been used rather sparingly, except in those cases where the general effect is desired rather than the actual details.

It is obvious that books prepared along the lines mentioned must not only be clear and concise beyond anything heretofore attempted, but they must also possess unequaled value for reference purposes. They not only give the maximum of information in a minimum space, but this information is so ingeniously arranged and correlated, and the indexes are so full and complete, that it can at once be made available to the reader. The numerous examples and explanatory remarks, together with the absence of long demonstrations and abstruse mathematical calculations, are of great assistance in helping one select the proper formula, method, or process and in teaching him how and when it should be used.

This volume contains papers on the subjects of rock boring, rock drilling, explosives and blasting, coal-cutting machinery, timbering, timber trees, and trackwork, and will be of service to prospectors and contractors for boring deep wells, shaft and slope sinkers, quarrymen, entry drivers, miners, machine runners and helpers, timbermen, trackmen, blacksmiths, mine machinists, manufacturers of mine machinery, blasting powder, and caps. The subjects are each treated in a manner to show its particular application to the work of mining. Many practical points are explained that cannot but prove of great value to all engaged in the work of mining coal or quarrying rock.

The method of numbering the pages, cuts, articles, etc. is such that each subject or part, when the subject is divided into two or more parts, is complete in itself; hence, in order to make the index intelligible, it was necessary to give each subject or part a number. This number is placed at the top of each page, on the headline, opposite the page number; and to distinguish it from the page number it is preceded by the printer's section mark (§). Consequently, a reference such as § 16, page 26, will be readily found by looking along the inside edges of the headlines until § 16 is found, and then through § 16 until page 26 is found.

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CONTENTS

ROCK BORING

THE AMERICAN DRILL RIG

INTRODUCTION

1. Historical.—The first well drilled for the express purpose of obtaining oil was sunk near Titusville, Pennsylvania, by Col. E. L. Drake, in 1859. Since that time probably 200,000 wells have been sunk in the United States by what is known as the *American drill rig*. At first it was a very tedious and expensive operation to drill a deep bore hole, but now it can be sunk 2,000 feet at a tenth of the cost, in about one-tenth the time, provided the drillers understand their business. The modern operation is an adaptation of steam power to the method practiced for ages in China. The principle is that of percussive boring; free-falling tools suspended by a cable and raised by steam power are used, the weight of the tools being so great as to give blows of sufficient force to pierce the hardest rock.

2. The Drill Rig.—A general idea of the **American drill rig** and its operation can be obtained from Fig. 1, which shows an elevation and plan. Derricks are usually constructed of wood, but Fig. 1 shows one made of steel. In the elevation, there is shown a rope *W* partially wound on a reel *B*, from which it passes up over a pulley at the top of the derrick and then down to the center of the derrick floor, where the hole to be drilled is situated. Here, during drilling operations, the rope is fastened to a temper screw *S*

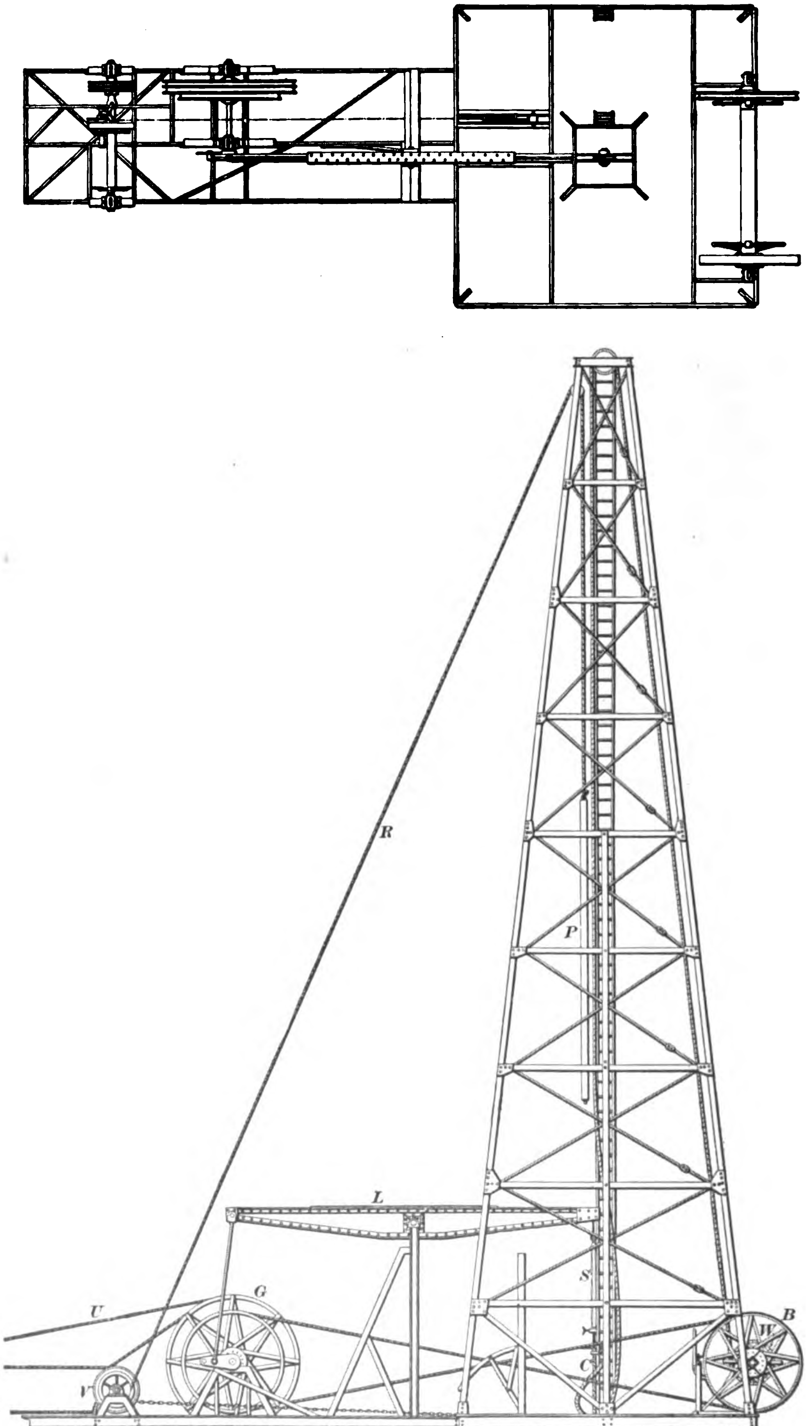


Fig. 1

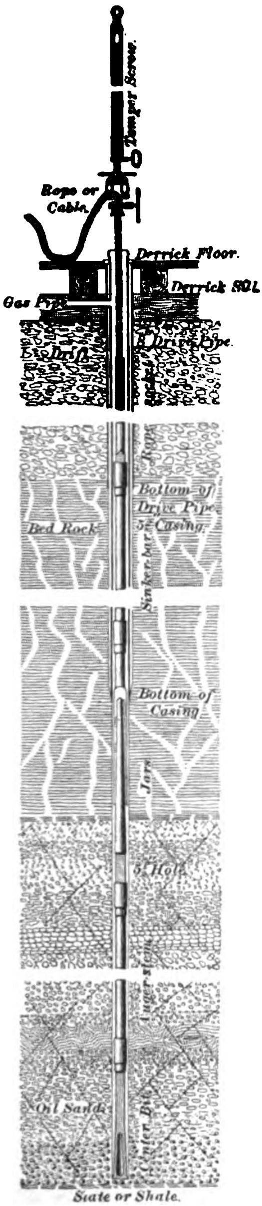


FIG. 2

by clamps, but its end is attached to a rope socket, that, in turn, carries the tools shown in Fig. 2 in the well. The temper screw is hooked to a walking beam *L*, Fig. 1, which by means of a pitman and crank at its other extremity raises and then lowers the temper screw with the drilling tools attached. In order to raise the tools from the bore hole, a rope belt *C* passes around the bull wheel *B*, and then around a tug wheel, attached to the band-wheel *G*. To raise the tools by the rope, the temper screw is released from the drill rope and the motion of the engine reversed, so that the bandwheel will transmit power in a direction opposite to that when drilling. Power is transmitted by an engine, not shown, to the band-wheel *G* by means of a belt *U*. As the drill advances into the rock, the cuttings would clog the hole, were they not removed, for which reason the rope *R* is attached at one end to a pump *P* and at the other to a reel *V*. The pump is raised from the hole by engine power, but lowered by gravity. The sand reel *V*, with the bandwheel, bull wheel, and walking beam, are shown in the plan.

3. The Boring Operation. — The height to which the tools are raised and then allowed to fall is about 2 feet. The drill stem and bit weigh about 1,200 pounds, and have an approximate end velocity of 6 feet per second. Then, from *Mechanics*, the average force of the blow is obtained as follows, supposing that the drill penetrates the rock ¼ inch:

$$\frac{6^2 \times 1,200 \times 4 \times 12}{2 \times 32.16} = 32,239 \text{ pounds}$$

This is equivalent to a blow of 16.1 tons.

Fig. 2 shows loose ground at the top of the hole. As this must be cased off before drilling can proceed, a drive pipe is forced through it for this purpose. Sometimes it is necessary to case holes to a considerable depth, or to stop up crevices, or to widen or ream out the hole, all of which operations, as well as the recovering of lost tools, enter into the subject, and need a more detailed description. For the purpose of explanation and detail, the American drill rig will be divided into the *carpenter's rig* and the *drill rig.*

THE CARPENTER'S RIG

4. Derricks for Carpenter's Rig.—That portion of the rig which includes the derrick foundation, derrick, derrick house, and woodwork generally has been termed the **carpenter's rig.** The rig may be divided into three sections: foundation, derrick, and auxiliary parts. Most of the rig is held together by wedges, but the derrick is nailed together when it is to be permanent and bolted together when it is to be removed. The rig is sometimes made of angle iron, but such derricks and rigs are not much used or liked by American drillers, because of their expense and the danger from lightning. Where suitable timber cannot be obtained, or where it would dry out and check sufficiently to warp and weaken the structure, as might be the case in hot and dry countries, the steel derrick and rig may be advantageously substituted. The following description and specifications of a carpenter's rig should be sufficient for any intelligent man to erect one in any country, where proper lumber can be obtained.

5. Ground Plan.—The sills, posts, and braces for a derrick 72 feet high, shown in Fig. 3 (*a*) and (*b*), occupy a ground space about 24 feet by 90 feet. In Fig. 3 (*a*) *a* are

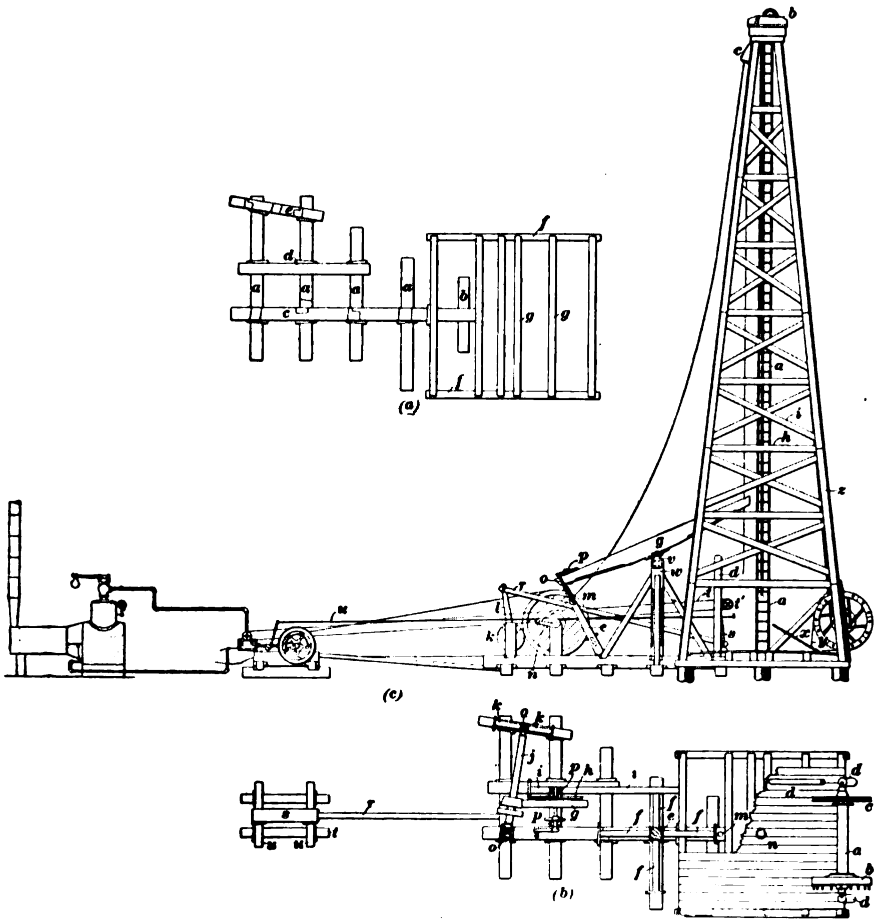


FIG. 3

mud-sills; *b*, nose sill; *c*, main sill; *c*, sand-reel tail sill; *f*, derrick mud-sill; *g*, derrick floor sills. In Fig. 3 (*b*), *a* is the bull-wheel reel; *b*, bull wheel; *c*, bull-wheel tug wheel;

d, bull-wheel braces and posts; *e*, samson post; *f*, samson-post braces; *g*, bandwheel; *h*, bandwheel tug wheel; *i*, band-wheel post braces; *j*, sand reel; *k*, sand-reel post braces; *o*, sand-reel posts; *p*, bandwheel posts; *m*, headache post; *n*, derrick floor; *r*, engine-block brace; *s*, engine block; *t*, engine-block mud-sills; *u*, engine pony sills.

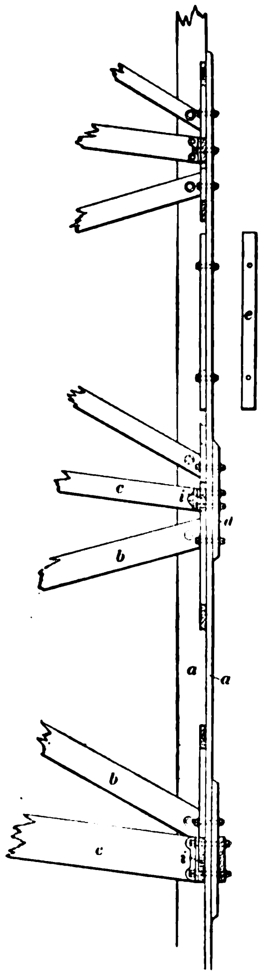


FIG. 4

6. Derrick.—The sizes for timbers and lumber given in the specifications correspond to a derrick 72 feet high. If necessity compels the use of smaller sizes of lumber, the deficiency in strength must be supplied by extra bracing. In countries where timber is expensive or where it is impossible to secure men competent to build a rig, the knockdown or bolted derrick is recommended, as it may be obtained ready to set up. Hard wood is used for the foundation timbers, but the derrick is made of pine with iron corner pieces, no nails being used. Each piece is numbered, so that the rig may be put together and taken apart as desired. The method of bolting a derrick together is illustrated in Fig. 4; *a* are the legs; *b*, the braces; *c*, the girts; *d*, the fish-plates; *e*, the stiffeners for the legs; and *i*, iron corner pieces.

7. Miscellaneous Details.—Fig. 3 (*c*) shows an elevation of a derrick and rig. A ladder *a* reaches from the floor of the derrick to the crown-pulley block *b*; the sand-sheave pulley block *c* can be reached by the same ladder. The headache post *d* is so named because it prevents the driller being knocked on the head in case the pitman *e* should break or become deranged and let the walking beam *g* be pulled down by the tools. The derrick legs are represented by *z*, the girts by *h*, and the braces by *i*.

TABLE I

TIMBER SPECIFICATIONS FOR SILLS, POSTS, AND BRACES FOR DERRICK 72 FEET HIGH

Mud-sills		14″ × 16″ × 20′
Mud-sills		14″ × 16″ × 16′
Nose sill		16″ × 18″ × 6′
Main sill		16″ × 18″ × 33′
Counter sill		16″ × 18″ × 16′
Sand-reel tail sill		12″ × 12″ × 12′
Derrick mud-sills		10″ × 10″ × 22′
Derrick floor sills		8″ × 10″ × 20′
Samson post		16″ × 16″ × 13′
Samson-post braces		6″ × 8″ × 14′
Samson-post braces		6″ × 8″ × 16′
Samson-post braces		6″ × 8″ × 12′
Sand-reel knuckle post	1 piece	16″ × 16″ × 8′
Sand-reel tail post	1 piece	12″ × 12″ × 5′
Bandwheel jack post	1 piece	16″ × 16″ × 8′
Bandwheel jack-post caps	1 piece	14″ × 10″ × 3′
Bandwheel jack-post braces	1 piece	6″ × 8″ × 16′
Engine-block brace	1 piece	6″ × 6″ × 33′
Engine mud-sills	2 pieces	14″ × 14″ × 14′
Engine block	1 piece	20″ × 20″ × 8′
Engine pony sills	2 pieces	2″ × 12″ × 8′
Bull-wheel posts	2 pieces	10″ × 10″ × 11′
Bull-wheel post brace	1 piece	6″ × 8″ × 14′

TABLE II

SPECIFICATIONS OF LUMBER FOR DERRICK 72 FEET HIGH

35 pieces	2″ × 8″ × 22′	for floor
4 pieces	2″ × 12″ × 40′	for legs
4 pieces	2″ × 12″ × 34′	
4 pieces	2″ × 10″ × 40′	
4 pieces	2″ × 10″ × 34′	
4 pieces	2″ × 12″ × 20′	for girths
4 pieces	2″ × 12″ × 18′	
4 pieces	2″ × 12″ × 16′	
4 pieces	2″ × 12″ × 14′	
4 pieces	2″ × 12″ × 12′	
4 pieces	1″ × 12″ × 10′	
2 pieces	1″ × 12″ × 16′	
2 pieces	1″ × 12″ × 12′	
1 piece	1″ × 12″ × 16′	
8 pieces	1″ × 6″ × 20′	for braces
8 pieces	1″ × 6″ × 18′	
8 pieces	1″ × 6″ × 16′	
8 pieces	1″ × 6″ × 14′	
8 pieces	1″ × 6″ × 14′	
8 pieces	1″ × 6″ × 12′	
4 pieces	1″ × 6″ × 16′	
4 pieces	1″ × 6″ × 14′	
1 piece	2″ × 12″ × 12′	for pulley blocks
2 pieces	4″ × 4″ × 10′	
144 lineal feet	2″ × 4″	for ladder
144 lineal feet	1″ × 4″	
Total, 3,448 feet	100 pounds nails	

WORKING PARTS

8. Bandwheel. — The common **bandwheel** is made entirely of wooden pieces, the straight pieces being termed arms, and the curved pieces cants. Fig. 5 shows a bandwheel in elevation; *a* are the arms; *b*, the cants; *c* is the bull-rope protector that keeps it off the tug wheel *d*, the latter being grooved to receive the rope when it is required to use power on the bull wheel.

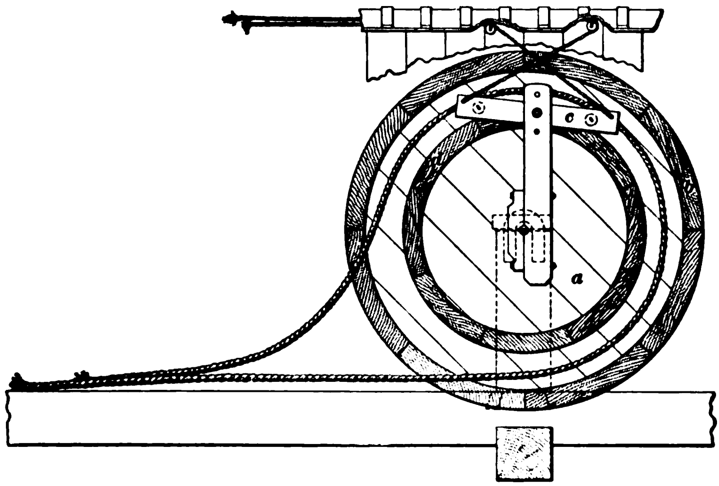


FIG. 5

9. Bull Wheel.—The common **bull wheel**, Fig. 6, is constructed of straight arms and cants. The wheels *a*, *b* are

FIG. 6

connected by an axle. The wheel *a* with the groove is termed the tug wheel; the other wheel *b*, the bull wheel.

The bull-wheel rope, which passes around the tug wheels of the bull wheel and bandwheel, acts as a belt to raise the drilling tools by winding the drill rope on the axle. The bull-wheel axle is supplied with gudgeons *d* at the ends for working in boxes in bull-wheel posts. The pins *e* are for turning the bull wheel by hand and thus taking up slack or letting out rope independent of the power.

10. The Sand Reel.—Fig. 7 is that part of the rig which raises the sand pump used for cleaning out the sludge from bore holes. It consists of an axle *a*, upon which is a wooden friction wheel *b* and a guide wheel *c*. The axle is provided at each end with gudgeons *d* for fitting into the reel posts. Fig. 8 shows the **sand reel** *k* to be connected by a lever *l* to a rod *r* that connects with another lever *s* in

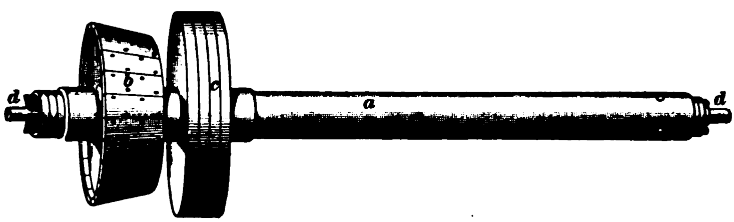


FIG. 7

the derrick. These levers throw the sand-reel friction wheel against the bandwheel *m*, and as the bandwheel turns, the sand pump is raised by the friction turning the sand-reel axle and winding up the sand-pump rope. To lower the pump into the hole, the lever is moved so as to throw the sand-reel friction wheel *k* away from the band-wheel *m*, when the weight of the sand pump will unwind the rope.

11. The Walking Beam.—As shown at *g* in Fig. 8, this is a large beam 12″ × 26″ × 26′, which is moved up and down by the pitman *e*, that connects with the bandwheel crank *n*.

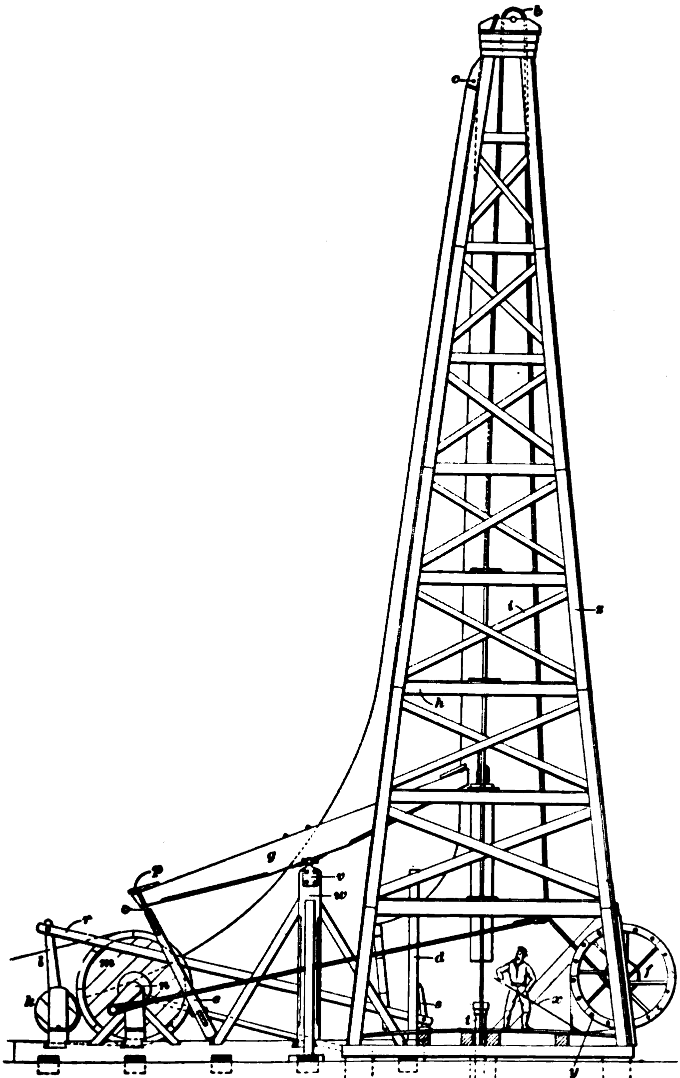


FIG. 8

The pitman hangs from the walking beam by a stirrup *o* that is kept in place by an adjuster board *p*. The length of the stroke may be varied by placing the wristpin in any of the crank holes shown in the bandwheel crank, Fig. 3 (*c*). The walking beam is fastened at its center by a saddle *v* to the samson post *w*.

12. Miscellaneous Details.—The **crown pulley** *b*, Fig. 8, placed at the top of the derrick is about 36 inches in diameter. The drill rope passes over it, and since the latter holds a heavy string of tools, the strain on the crown pulley is severe when hoisting, and care must be used to place its axle properly in the boxes. The **sand-pump pulley** *c* is about 18 inches in diameter and has not as much stress to withstand as the crown pulley; however, it should be strongly braced at its bearings.

The telegraph cord *t*, Fig. 3 (*c*), connects the small pulley *t'* with the throttle valve of the engine. A reversing rod *u* changes the motion of the engine when it is desired to hoist the tools from the drill hole; for when drilling, the engine usually runs in a direction opposite to that when hoisting. A lever *x* that applies the brake strap *y* to the bull wheel permits the tools to be lowered into the hole by gravity.

THE DRILL RIG

13. Oil-Well Engine.—An **oil-well engine** is shown, in Fig. 9, mounted on a block. *a* is the throttle-valve pulley wheel; *b*, the reverse lever; *c*, the pump; *d*, the belt pulley for driving the bandwheel. These engines have sectional flywheels *e* constructed so that when necessary they may have a greater counterbalance. The boilers for supplying steam to the engines are usually of the locomotive-boiler type, but any portable boiler will answer. The engine feeds water to the boiler by means of the pump, which has a plunger and working barrel attached to the crosshead of the engine, but not shown in the figure. Engines for well drilling are usually about 20 horsepower, and drive the bandwheel by

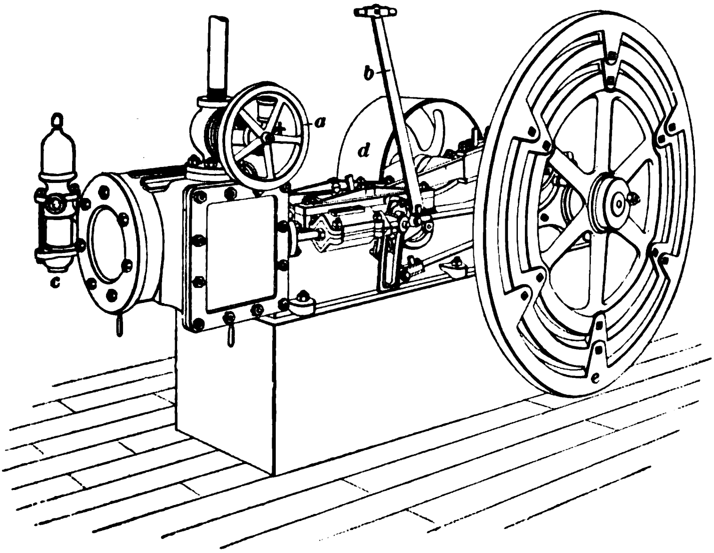


FIG. 9

an 18-inch four-ply rubber belt. To economize in fuel, the exhaust steam is passed through a feedwater heater attached on the pump side of the engine.

DRILLING TOOLS

14. The **tools** consist of a rope socket, sinker bar, jars, stem, and bit, weighing together about 2,000 pounds when the string of tools is 61 feet long. Besides the above, the temper screw, wrenches, hawser-laid drill rope, and sand pump are factors in boring. Accessory tools, such as anvil, forge, sledge hammers, bellows, and gauges, are also necessary for sharpening bits. Fishing tools for recovering the rope, if it breaks, or the tools if they break or become loose in the bore hole are numerous, and consequently cannot all be mentioned.

15. Rope Socket.—The **sockets** are fastened to the drill rope in various ways. Probably as servicable and easily worked a socket as any is the *wing socket*, shown in Fig. 10. The rope is put through the wings, which are afterwards drawn tight by rivets driven through the holes

FIG. 10

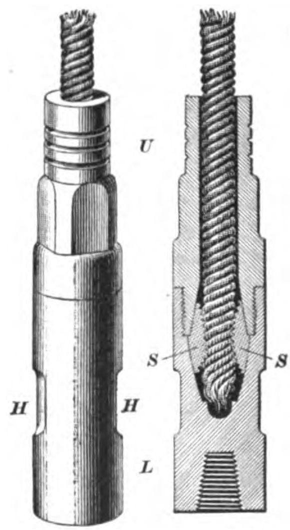


FIG. 11

shown. Another rope socket is shown in Fig. 11. The rope is passed through the upper portion U and the jaws S; the upper U and lower portion L of the socket are then tightly screwed together, thus clamping the jaws so that they grasp the rope firmly.

16. Sinker Bar.—The upper end of the **sinker bar** shown in Fig. 12 is provided with a male screw H for fastening it to the lower end of the rope socket F, which has a female thread. This bar is 3¼ inches in diameter, 18 feet long, and weighs about 540 pounds. It is provided at each end with square shoulders for the purpose of taking the wrenches when stringing and unstringing the tools. The function of the sinker bar is to afford weight and deliver an upward blow to the stem and bit, thus loosening them and preventing their sticking in the hole. It does not deliver a downward blow. The weight and diameter of the sinker bar must be proportioned to the diameter of the hole being drilled.

FIG. 12

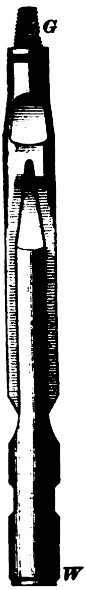


FIG. 13

17. Jars.—This tool divides the string of tools into two members, and is merely a long link with a female thread in box *W* at one end and a male thread *G* at the other. In Fig. 13 the jars are shown closed. They are about 7 feet 6 inches long from end to end, and when open lengthen considerably. The jars are usually allowed a play of about 13 inches when drilling; that is, on the up stroke before the upper link strikes the lower. On the down stroke the links are not permitted to strike; for instance, if the stroke is 24 inches, the sinker bar and top jar move 4 inches upwards and then pick up the lower tools with a jerk and raise them 20 inches. On the down stroke the auger stem and bit fall 20 inches, while the sinker bar falls 24 inches to telescope the jars and have 4 inches play for the next blow coming up. A skilful driller never allows his jars to strike together on the downward stroke; as the jar grows weaker by reason of the hole advancing, he tempers the stroke by means of a temper screw, thus giving the jars more play. A set of jars are 5½ inches in diameter and weigh about 320 pounds.

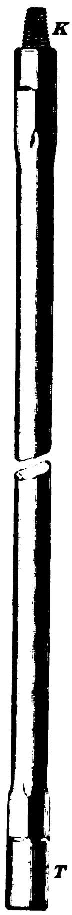


FIG. 14

18. Auger or Drill Stem.—This part of the string of tools is a duplication of the sinker bar, but is made about 30 feet long in some cases; it has a diameter of 3½ inches and weighs about 1,020 pounds. It is also provided with a pin *K* at one end, Fig. 14, and a box *T* at the other, with a collar for the wrenches. It is the weight of the sinker bar in falling that gives force to the blow of the drill. If the drill is too heavy, there will be too much vibration to this stem, and either the stem will become unscrewed or broken.

19. The Bit.—This is the lowest member and does the cutting. It is shown in Fig. 15, and for an 8-inch hole will

FIG. 15

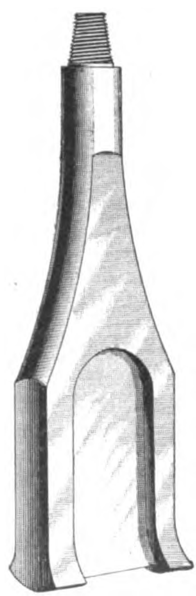


FIG. 16

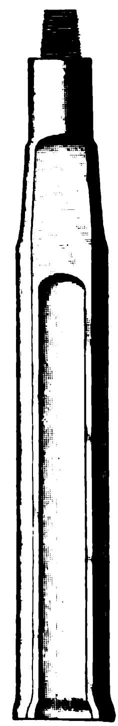


FIG. 17

probably weigh 160 pounds. The spudding bit in Fig. 16 is for drilling earth down to solid rock, while the **reamer**, Fig. 17, is for giving the hole a larger diameter.

20. Temper Screw.—To the walking beam of the drill rig the rope carrying the tools is attached by means of a **temper screw.** This appliance, shown in Fig. 18, is divided into a link *A* termed the reins, a screw, and the clamps. The reins are provided at the top with an eye *E* for taking the hook depending from the walking beam, and at the bottom with a yoke or split nut *J*, to one side of which is fastened rigidly a collar provided with a hand screw for tightening the split nut.

The screw is about 1⅝ inches in diameter and 4 feet long, having two square threads to the inch, with swivels at both the top and bottom. The top swivel bar prevents the screw from lashing during drilling operations, while the bottom swivel *H* is for turning the rope during drilling. From the swivel crosshead *H* two links depend, one carrying a clamp socket *S* to which the vise is attached, and the other carrying the loose socket on the side *T*. Both rope sockets are shown, in position, clamped to rope *R* for drilling, having been firmly fastened in the vise clamp by the vise screw *L*.

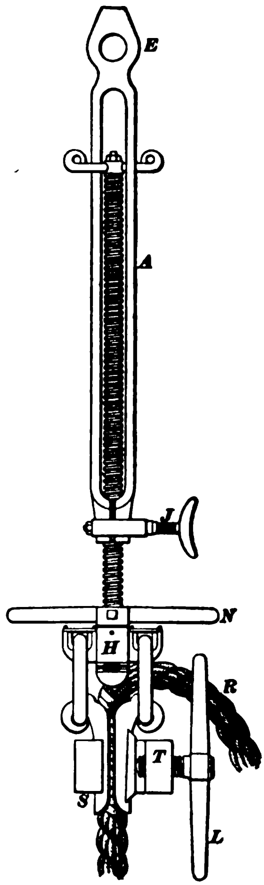


FIG. 18

21. Wrenches.—Each tool is provided with a square collar for the purpose of screwing up or unscrewing it by means of the **wrenches** *a* shown in Fig. 19. One wrench is attached to the collar of the tool underneath and the other to the tool above, then by placing a pin *b* in the floor circle *c*, the lower tool is prevented from turning by the wrench handle, while the upper tool may be turned by the wrench.

To turn the upper wrench, it is necessary to use the circle bar *d*, as shown. There are several patented arrangements for tightening and loosening the tools, which may possibly make the work easier, since the tools must be screwed as tightly as two men can make them by their combined strength. About one-half the losses of tools arise from not properly screwing the joints together, and about two-thirds of the balance are due to using poor material.

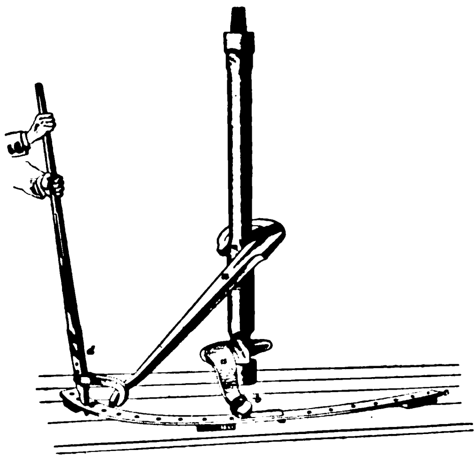


FIG. 19

After a joint has been set up solid, a slight mark may be made across it with a sharp cold chisel, half of it on the pin collar and half of it on the box. Each successive time this joint is screwed up, the mark on the box should go a little past the mark on the pin collar; if it does not, it indicates that there is dirt on the face of the joint or in the threads, which should be removed; otherwise, the dirt may work out and cause the joint to become loose.

SHARPENING THE TOOLS

22. Dressing the Bits. — Fig. 20 shows a properly dressed bit, with tool gauge for ascertaining its fitness. A different tool gauge is required for each diameter of bit, which should fill out the gauge so that the corners from *a* to *f* have the same distance as from *c* to *b* or from *c* to *d*. The bit should be heated in the forge to a cherry-red for a distance of 3 or 4 inches back from the point, being turned occasionally in the fire to get both corners hot. Drillers sometimes make a mistake in not heating the bit far enough back, since if a bit is heated on the point only, hammering spreads the surface but not the center, and later on the surface peels off. The heated bit is placed on an anvil for dressing and is spread somewhat larger than a finished bit by striking it with a sledge at the center first and following the blows out to each corner; the bit is then turned and hammered in the same way on the other side. It is then turned on a narrow side so as to project a little over the anvil and the corners given cutting edges. This is the most important part of the dressing, since the corners do nearly all the cutting and they must conform to the gauge in order to drill a round hole and not cause the drill to stick. The edge, when hammered into size and shape, will do twice as much cutting as when dressed with a file. Finally the bit or cutting edge from *b* to *c* must be straightened. One-half of the art of drilling is knowing how to temper and dress a heavy bit properly. While almost any coal may be used for bit dressing, it should be as low in sulphur as possible, as sulphur in coal is bad for the bit.

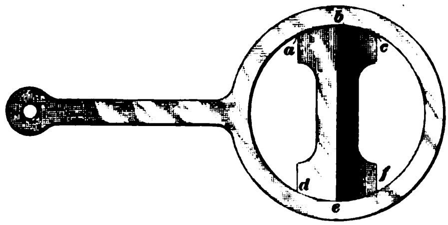


FIG. 20

23. Anvils.—Most drillers prefer the ordinary blacksmith **anvil**, but many on account of weight and the

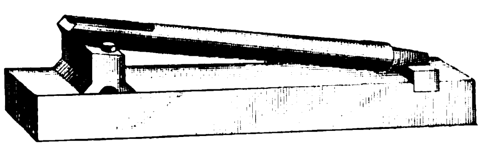


FIG. 21

convenience in turning the bit when drilling prefer the block shown in Fig. 21.

TEMPERING BITS

24. Heat Colors.— The colors that show on heated steel appear different, according to the light or shade they are in; for instance, a dark cherry-red in sunlight will have a brighter shade of red in a darker light. When tempering the bit, therefore, it should be heated to a dark cherry-red in sunlight, but should never be heated so strongly that it throws off sparks, as this indicates that carbon is being burned out of the steel. The bit should be evenly heated for at least 3 inches back of the cutting edge; then it should be set perpendicularly as shown in Fig. 22, so that about 1½ or 1¾ inches of water will be above the bit.

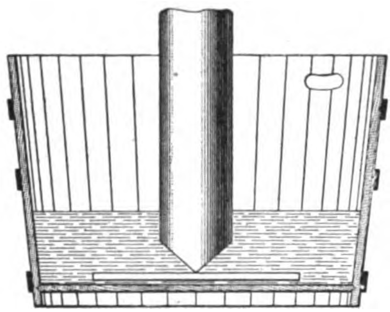


FIG. 22

The water in the tub should be stirred until the edge of the bit has become cooled; the tool should then be tilted out of the water, where the cutting edge may be rubbed with a stone to remove the scale.

The succession of colors that creep gradually toward the point of the bit are carefully watched, until the deep purple or blue runs down to within ¾ inch of the cutting edge. Then the drill is stood upright again in the water and allowed to cool off.

25. Tempering Color.—The first color to appear on the bit may be nearly white, the next straw or orange, followed in succession by a deep yellowish-purple, blue, and finally black. The white color gives too hard a temper to the bit for any but soft rocks, such as slate and crystalline limestone; the straw and orange would also give too brittle a temper for hard rock and probably cause the edges of the bit to chip. The deep purple or blue is about right for the hardest rock, while black is too soft and causes the edge to become battered in a short time. After having tempered these bits a few times, the operator will learn to gauge by sight the color that will produce the best temper for the steel and the rock. In some instances the expert judges from the color to which the bit is heated what temper may be obtained, and does not need to lift the drill from the water to watch for the colors.

26. The Tempering Water.—The reason for not tempering in deeper water is that the heavy bit of steel will not quickly cool to the center, while the outside shell will cool, contract, and may even crack open. The cracks thus formed become deeper at each heating and cooling until pieces chip off. The better the steel and the higher the carbon, the more likely is this to occur, but it can easily be avoided by tempering in shallow water as previously described, and only tempering that part which has been hammered. The bit should always be dressed out to the full gauge of the hole to be drilled, as it will otherwise become smaller as the depth is increased. The gauge should be put on the bit each time the hole is sludged, and if not up to gauge it should be dressed, or a dressed bit substituted. The tool dresser should see that the threaded end of the bit is entirely cold before it is put on for drilling; otherwise, the screw may shrink and loosen the joint after the tools have been lowered into the hole.

MISCELLANEOUS APPLIANCES AND OPERATIONS

27. Conductor, or Stand Pipe.—Before drilling can be carried on, the surface soil must be cased off and the rock penetrated sufficiently to permit a string of tools 60 feet long to hang in the hole. The **conductor,** or **stand pipe,** may be made of planks nailed at the corners or it may be large wrought-iron pipe. If the ground is tight, a bit may be used to loosen it as this stand pipe is being put down. It may be necessary, where the drift is thick, to drive the stand pipe several hundred feet. There are two methods of driving pipe, which are equally effective.

The method of driving pipe with a mall is shown in Fig. 8, *t* being the pipe. Where this method is practiced, a solid drive head, Fig. 23, is required to prevent the threads and upper end of the pipe becoming mashed. For a similar reason, a drive shoe, Fig. 24, with a beveled edge is placed on the lower end of the drive pipe.

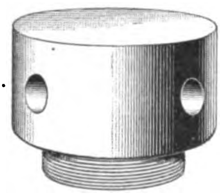


FIG. 23

On account of the labor connected with rigging up a mall with guides, it is now customary to use the drill stem and bolt to it a pair of driving clamps. This arrangement is shown in Fig. 25 (*a*) and (*b*), where *a* is the drill stem; *b*, the drill bit; *c*, the drive shoe; *d*, the hollow drive cap; *e*, the driving clamps, better shown in elevation, Fig. 25 (*b*). If the drill is allowed to go just ahead of the drive pipe, it will be much easier to drive the pipe. The material driven through should be sludged out every 3 or 4 feet, pouring water down the hole for this purpose, if necessary.

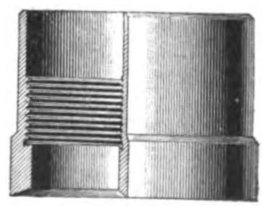


FIG. 24

28. Spudding.—Before a depth sufficient to take a 60-foot string of tools is reached, it may be necessary to drill by **spudding.** In soft ground the tool used for this purpose is a large bit—in every case this is larger than the diameter of the hole to be drilled, for the casing must go a short distance into the rock. The operation of spudding is carried on without the walking beam in the same manner as that illustrated for driving the tubing in Fig. 8.

If the ground will stand alone, the conductor or drive pipe, can be driven down independent of the bit. The conductor should be at least 10 inches in diameter, and may have an outside coupling *T*, as shown in Fig. 26. Since it may be necessary to case off water, or loose ground deep down in the hole, a larger diameter than the drill is necessary, because the casing pipe must go inside the stand pipe, as shown in Fig. 2. Each casing pipe inserted in the hole will diminish the diameter of the bit by a little more than twice the thickness of the casing pipe.

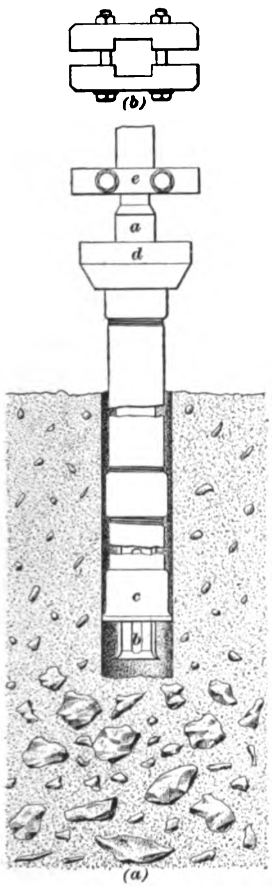


FIG. 25

29. Stringing the Tools. When sufficient depth has been reached for a string of tools, spudding is discontinued. In stringing the tools care must be taken to see that they are properly tightened; otherwise, they will unscrew in the hole. After all the joints have been screwed up the tools are lowered into the hole by means of the bull-wheel brake. The band-wheel crank is then turned to the upper center and the pitman raised and slipped upon the wristpin, where it is secured by the key and wedges; the temper screw is hung upon the walking-beam hook; and the slack in the cable is then taken up by the bull wheel until the jars are known to

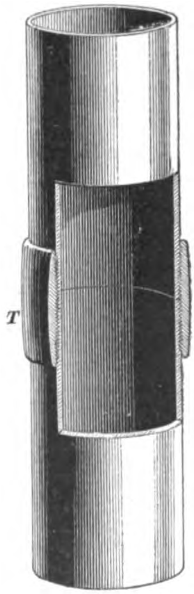


FIG. 26

be in proper position. The clamps are brought around the cable after that has been wrapped where it comes in contact with the clamps, and then the latter are securely fastened by the clamp screw. The cable is next slacked off from the bull wheel, and the tools held in the well suspended from the walking beam instead of from the crown pulley of the derrick, as before. The engine is next started and the walking beam moves up and down, alternately raising and lowering the tools, the driller in the meantime rotating the drill rope so that the bit will not strike twice in succession in the same place. When the drill is rotated in one direction for some time, the slack rope hanging from the crown pulley, which is allowed to be upon the floor, coils around the drill cable; when it becomes troublesome the motion is reversed and it uncoils. Only by this constant rotation of the drill can a round hole be insured. As the drilling proceeds, the hand screw on the collar of the reins is loosened and the temper screw lowered by turning the handle at the lower end; the reins are then tightened and the drilling continued until the jar informs the driller that the temper screw should be again let out. This is continued until the entire screw has been let out.

FIG. 27

30. The Sand Pump.—When the cuttings in the hole become too deep to allow the drill to drop freely to the bottom, they are removed by means of the sand pump. The common **sand pump,** Fig. 27, consists of a working barrel *a*, cut away at the lower end in the illustration, to show a dart valve *b* provided with shoulders to prevent its being forced too high into the barrel when the pump descends into the hole. The pump is attached to the sand rope by the bail *c*. The cuttings in the form of sludge enter the pump at the lower end, the valve closing and preventing their flowing out when the pump is raised. Should the mud in the well be so thick that the pump will not readily sink to the bottom, it is raised and lowered alternately until filled, when it is drawn up and emptied. This process is repeated until the hole is cleared.

31. Vacuum Sand Pump.—Fig. 28 shows the **vacuum sand pump** with a portion of the working barrel removed to show the valve and sucker rod. *a* is the barrel, *b* is the valve, or sucker, that travels the whole length of the pump barrel. When the pump is lowered into the well the sucker goes to the bottom of the pump, being forced down by a heavy iron sucker rod *c*. The sand line is securely fastened to the top *d* of the sucker rod, and when the sand reel is thrown in gear the sucker is drawn up rapidly, creating a vacuum that draws the sludge into the pump barrel.

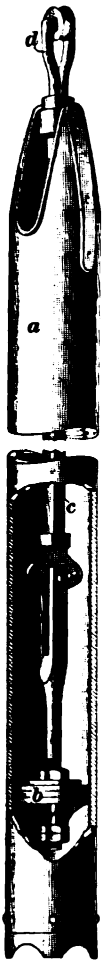


FIG. 28

32. Drill Ropes.—Fig. 29 shows a drill cable of three small ropes of three strands each twisted together, termed a *hawser-laid cable*. Hawsers are almost entirely used for sand lines and drill ropes, since they are strong and elastic. Ropes in deep holes must have elasticity, as they stretch considerably with a heavy string of tools on them irrespective of their own weight; in fact, it is this elasticity of the rope coupled with the jars that makes the American drilling rig so effective. Manila drilling cables have usually diameters of $1\frac{7}{8}$, 2, $2\frac{1}{8}$, and $2\frac{1}{4}$ inches, and can be purchased in any length up to 4,600 feet. The breaking strength of manila rope may be found by squaring the circumference in inches and multiplying the product by 790 for new rope and 1,050 for sound old rope. As rope is


FIG. 29

purchased by the pound and a running foot varies in weight, the buyer should always request the weight per foot with the price.

33. Other Ropes Required.—Sand lines are usually $\frac{7}{8}$, 1, and $1\frac{1}{8}$ inches in diameter, as in deep holes they have considerable strain placed on them. Sucker-rod lines are used from $1\frac{1}{2}$ inches in diameter up to 2 inches, while tubing lines are used from 2 inches to $2\frac{1}{2}$ inches in diameter. Bull-wheel driving ropes are of hemp, $2\frac{1}{2}$ inches diameter, and plain laid.

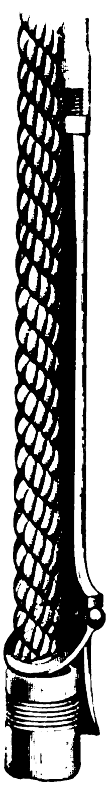


FIG. 30

34. The Rope Knife.—Whenever tools are fast in the hole, so that they must be fished for, the rope must be cut. The **horseshoe rope knife** with guide is used for this purpose generally, although there are several other kinds of rope knives. Fig. 30 shows a horseshoe knife with guide cutting the rope. The knife blade is placed around the drill rope and the tool fastened to a string of sucker rods or a sand line with a sinker, the object being to carry the knife down to the tools. A few jerks on the line and knife will then cut the rope. These knives are made with a trip, so that the rope will not be cut until the trip has reached the rope socket, and permits the knife to fall. This arrangement is probably the best of all.

35. Rope Grabs.—In case the rope breaks, it is apt to tangle up in the hole, and if a proper **grab** is employed it may soon be caught and the tools extracted. The grab shown in Fig. 31 is in position to take hold of a rope end. When, however, it is desired to hoist, the wing *a*, which hinges at *b*, is pulled toward the wing *c*, and fastens its spurs into the rope. The **spear grab** is a single prong with spurs arranged spirally along its length, and will be found useful in case the rope is snarled in the hole.

FIG. 31

36. Fishing Tools.—Grappling tools are numerous and are constructed with many objects in view; hence, to describe them would exceed the scope of this section. For instance, a horn socket may answer for a loose tool, while in another case one to take hold of a pin will be required. Possibly a broken jar, stem, or bit grab may be required, or after a rope has been cut, a grab for the rope socket. Other fishing tools may be required to recover bailers, or sucker rods; to knock jars loose when they are locked in the hole; to drill holes into the tools; or put threads upon them in order to obtain a firm hold. In some cases all fishing devices will fail, and then the hole should be reamed and the calyx used to drill around the top tool in the hole, so that the fishing tool can reach it and get a firm hold. When this last plan fails, the tools and hole may be considered lost.

37. Reaming Bore Holes.—In measures with but little inclination the tendency of the drill is to cut exactly vertically, but in pitching measures there is a tendency of the bit to leave a vertical line when passing from a comparatively soft stratum into a harder one. This tendency is so strong that even most experienced drillers are sometimes unable to overcome it, though, as a rule, competent drillers detect it quickly, and take steps to prevent it. A hole not vertical throughout its whole length is very troublesome if for any reason it is desired to case it throughout or to pass a haulage rope through it, because the rope will strike the sides and will in a short time be ruined.

Fig. 32 shows a method of straightening a hole. The drill stem *a* is bushed by the guides *b*, which prevent its not confined to this use, their object being to enlarge holes. It is often easier to bore a 6-inch hole and ream it to 10 inches in diameter than to bore a 10-inch hole.

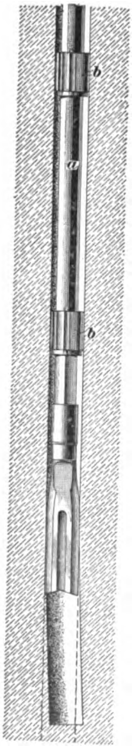


FIG. 32

38. Casing Holes. In **casing holes,** the general plan is to use a casing whose outside diameter is slightly less than the diameter of the hole, the space between the pipe and hole being carefully filled with Portland cement. In case the hole meets a fissure in the rock that drains it or admits surface water, *seed bags* are used to close such crevice until the casing is put in. They are also used to make a packing at the end of the casing tube previous to putting in the cement. These seed bags are small bags filled with flaxseed, which rapidly swells when wet, and thus fills up the space to be closed. The cement poured in the hole is drilled through after it is set, and if it is good cement, a tight joint between the casing pipe and rock will have been made.

FIG. 33

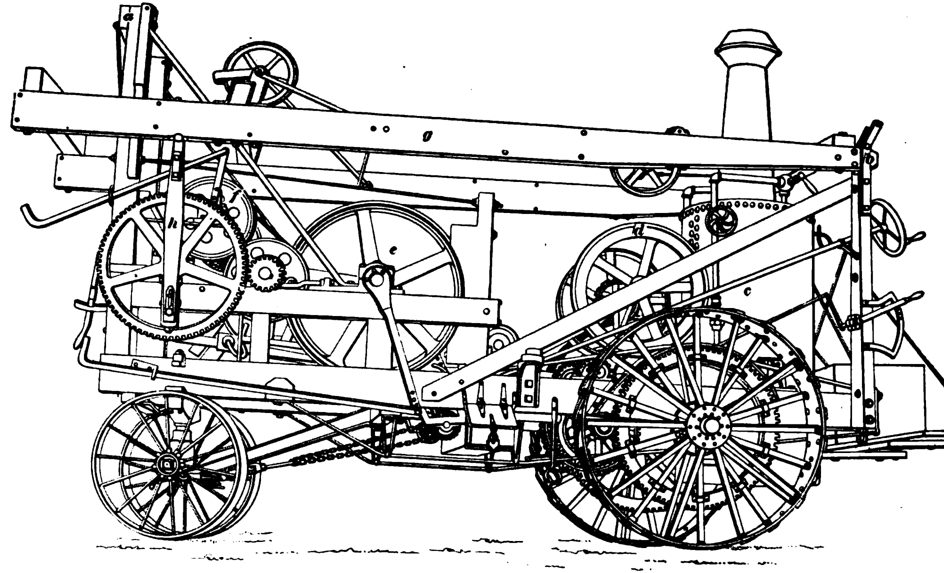


FIG. 34

PORTABLE DRILLING MACHINES

39. In many instances drill rigs mounted on wheels for transportation are very convenient, especially in testing placer or other shallow deposits; or for drilling holes not over 1,000 feet deep. Such **portable drill rigs** may have traction connections similar to those shown in Fig. 34, so that they can be moved about by their own power. Where a number of holes of moderate depth are to be bored, nothing can equal them if the object sought is not beyond their capacity. The derrick is not shown in the illustration, but is made of a height to correspond with the string of tools used for drilling; and it is also portable, hinging when in place to the post *a*, and being braced back to the post *b*. In the illustration, *c* is the boiler; *d* is the engine flywheel, the engine being almost out of sight; *e*, the drill-rope drum; *f*, the sand-rope reel; *g*, the walking beam; *h*, the pitman for the walking beam. The drilling machinery is all driven from a belted countershaft, and is thrown in and out of gear by means of a hand lever; in fact, the machine is complete in itself, but in case a hole of 500 feet or more is to be drilled it is advisable to erect a derrick, as it will handle a longer string of tools than the portable form.

PUMPING

40. The American drill rig is used for many purposes about mines, among which may be mentioned boring for water for coke oven, boiler, or domestic use. Incidentally gas and possibly oil may be struck, or water not suitable for use, in which case the driller should know how to handle them properly; that is, case off an undesirable product or pump what is desirable. The deep-well pumps mentioned here are of peculiar construction and intended for this character of work alone.

In case a well is to be tested to ascertain the quantity of water it will afford, it is customary to run into the water a pipe having at its lower end the working barrel of a lift pump, and use a set of sucker rods with a clack valve that fits snugly into the working barrel. One end of the sucker, or pump, rod is fastened to the walking beam and the engine started.

The method followed for pumping oil wells is shown in Fig. 35, and will illustrate nearly every case likely to occur. In the illustration, *a* is the walking beam; *b*, the sucker rod; *c*, the discharge pipe for oil; *d*, the casing head, with gas-pipe attachments *e*. The working barrel and inside casing through which the oil is pumped, or in some cases water, is shown in position with the drive pipe. When water is to be pumped, the casing head will not be needed with this method of pumping.

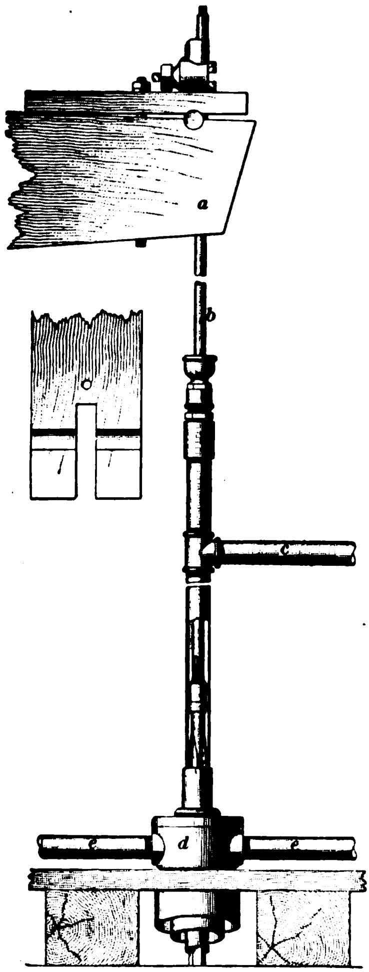


FIG. 35

41. Working Barrel. Where the drilling engine or some other engine is to be used in connection with the walking beam for pumping, a special kind of working barrel is placed on the end of the well pipe. A common **working barrel** is shown in Fig. 36, with a portion cut away to show the interior arrangement of the valves. The pump, or sucker,

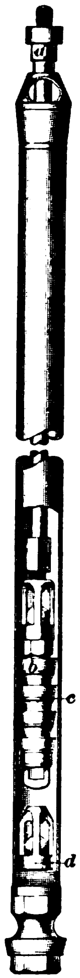


FIG. 36

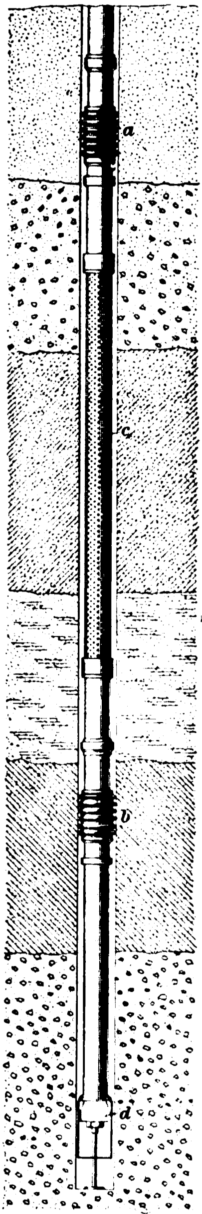


FIG. 37

FIG. 38

rod *a* is fastened to a number of sucker cups *b* having leather valves *c* that make a tight joint with the working barrel. To prevent the water going out of the barrel on the down stroke and to admit water on the up stroke, a foot-valve *d* is screwed into the lower end of the barrel. Pumps of this description are serviceable and at times economical; besides, the valves are readily replaced or repaired by simply raising the sucker rod. The lashing of the rods and their liability to become parted are objections that are common to every class of deep-well pumps.

42. Packers.—Fig. 37 shows the section of a gas well, with packer *a* to prevent gas going up outside the casing pipe, and packer *b* to prevent salt water mixing with the gas that enters the perforated pipe *c*. At the bottom of the hole will be seen what is termed a bottom packer *d*. This is better illustrated in Fig. 38, which shows a cone *a* drawn out and fastened to some easily broken material. When the disk reaches the bottom of the well and the weight of the tubing comes on the cone, the plug will be forced tightly into the pipe and prevent any salt water going up through the tubing. The packers *a* and *b* are telescopic joints with sheet rubber on the outside. When the weight of the pipes come on the packer, the joint pipe of the packer, being of smaller diameter than the casing, slides into the latter, thus making the rubber take the crimped form shown in the illustration, and pack the hole.

43. Pumping Powers.—Where several oil wells are to be pumped from one central station, a wooden or iron **pumping power** is installed. These powers are driven by a belt attached to the pulley wheel of a steam or gas engine. In Fig. 39, *a* is the belt wheel that drives a pinion *b*, which in turn drives a gear-wheel *c* attached to a vertical shaft *d*. To the shaft are keyed eccentrics *e* that turn with the shaft, and in so doing give the shackle rods *f*, *g*, and *h*, running out in different directions, a forward and backward movement, thus raising and lowering the pumping jack, or grasshopper, over the well. The shackle rods may be wooden as at *f*, wire rope as at *g*, or iron as at *h*. The

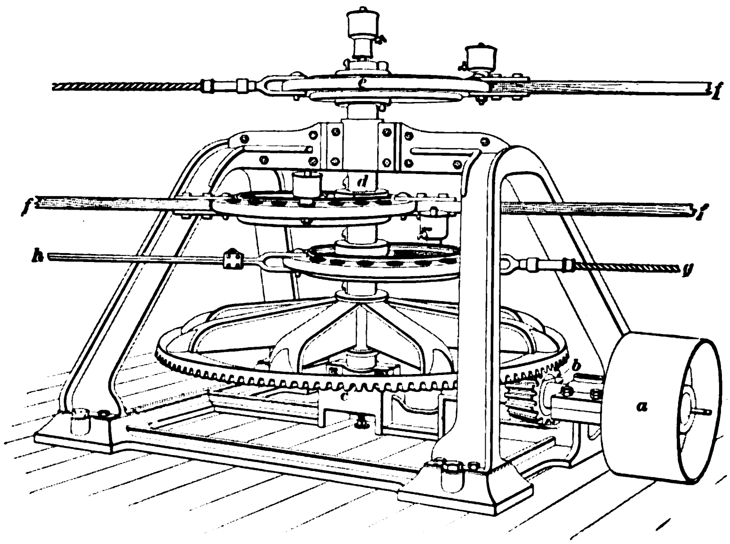


FIG. 39

eccentric works in a collar surrounding it, and to which the shackle rods are attached. This collar does not revolve with the eccentric.

44. Shackle rods are of wood, bar iron, or iron wire. The wooden shackle rods must be kept off the ground by the use of rocking beams, and this, together with their hooking up, makes them expensive in the long run. Bar-iron shackle rods are quicker to join, and may be driven over without injury. Their first cost is more than wooden rods, but being more durable, they are less expensive in the end.

45. Pumping Jacks, or Grasshoppers.—In Fig. 40 is shown a wooden **pumping jack**, termed a **grasshopper.**

The shackle rod *a* coming from the power, pulls and pushes the **V** jack knee *b*. To the knee jack and the walking beam *c*

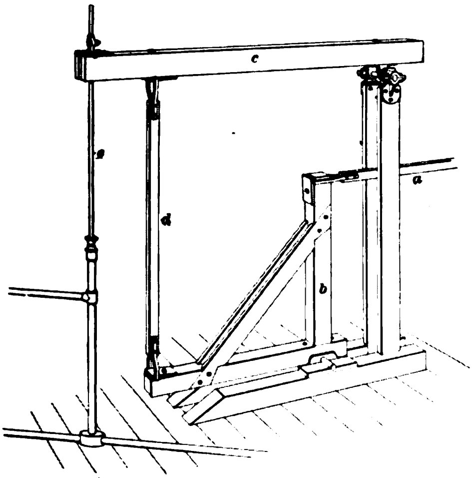


FIG 40

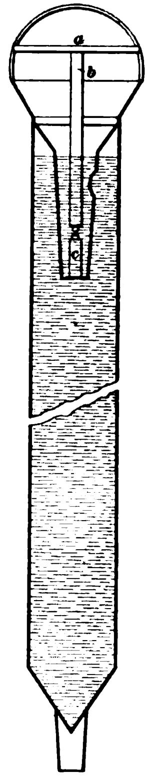


FIG. 41

is attached a pitman *d* that raises and lowers the pump rod *e*.

46. Shooting Wells.—When wells will not furnish a good supply of water or oil, as a last resort it is customary to shoot them, using for the purpose a torpedo similar to that shown in Fig. 41. Nitroglycerine is the explosive, and is discharged by means of a weight, or go-devil, dropped down the well on to the disk *a*. The impact of the go-devil on this disk drives a spindle *b* on to the cap *c*, thus causing an explosion. By attaching a string to the torpedo, it may be lowered and exploded at any desired depth. Special men are employed to shoot oil wells. The tins holding the nitroglycerine are lowered into the hole from a reel. They are made less in diameter than the hole, pointed at one end and open at the other. Each tin contains about 20 quarts. The cost of shooting, including the glycerine, is about 70 cents per quart, but there is usually a discount for cash payments.


FIG. 42

47. Plugs.—In some instances when water or oil is struck, the bore hole is continued with the expectation of obtaining a greater flow. If such expectations are not realized, it may be found advisable to plug the hole, with some such arrangement as that shown in Fig. 42. The hollow wooden plug *a* is put in the hole first and the head *b* afterwards. A few blows from a tool will spread the hollow plug and stop up the hole. These plugs are used also for stopping dry holes, that is, holes that have been bored for mineral and were failures, or when only gas was struck.

MODIFICATIONS OF THE AMERICAN DRILL RIG

48. Ground Testing Devices.—Among the numerous devices for the purpose of better determining the character of the ground that the drill passes through, than by the ordinary sludge pump, two have been successful, particularly in prospecting. One depends on the vacuum pump to remove the borings; the other on a hollow drill and rod that, having a ball valve, acts like a lift pump. Each system requires that the holes bored be cased with strong wrought-iron pipe, which may be withdrawn when boring is completed.

49. Keystone Drilling Machine.—This is a portable machine, the prospecting features, however, alone are given. When in drilling a stratum or a depth is reached in which minerals are suspected, the drill is kept sharp at the corners, and only a few inches drilled at a time. The vacuum sand pump is lowered into the hole, and when drawn up its contents are discharged into a bucket of water. It is important that a correct record of the depth be kept, and this is accomplished by fixing a piece of wire or cord through the drilling cable at a fixed point above the surface and the cable measured as it comes from the well. A memorandum should be kept of the exact distance drilled and, if minerals are found, the amount in bulk or percentage recovered in each distance drilled should be noted. The drillings should be preserved in glass bottles for future reference, and every change of rock with the thickness of each stratum noted.

50. Prospecting for Coal.—As a practical illustration, assume that the driller is looking for coal. It is desired to ascertain in such cases, the cover, the nature of the roof, and the thickness of the bed. The depth of the cover and the thickness of the coal are ascertained from measurements of the rope. The nature of the cover and roof is ascertained from the borings pumped out and placed in bottles. When the coal has been reached and a measurement made of the depth, the drill with a 6-inch bit, for instance, is removed and a long-shanked drill with a 3-inch bit substituted. With the latter the operator proceeds to cut a few inches at a time until the bottom of the vein has been reached. The 3-inch bit has a shank 8 feet long, or long enough to pass through an average coal seam. The cuttings are removed from this 3-inch hole by a 3-inch vacuum sand pump. When the bottom of the hole is reached and has been cleared, another measurement of the rope is made to give the thickness of the coal. The 3-inch center bit is next removed, and a

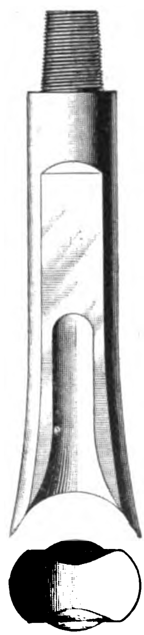


FIG. 43

shearing bit, Fig. 43, 6 inches in diameter, substituted, and drilling carried on 6 or 8 inches at a time, using the 3-inch vacuum pump for removing the drillings. This shearing bit will furnish fair-sized chunks of coal, from which its quality can be determined. Fig. 44 shows the drill *a* just

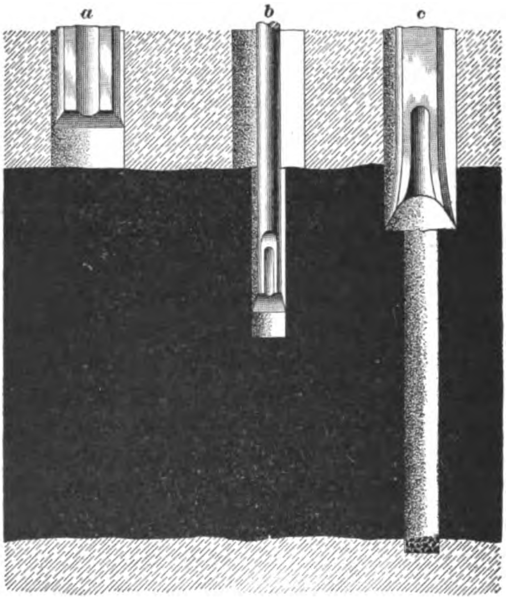


FIG. 44

above the coal; the 3-inch center bit *b* drilling into the coal, and the shearing bit *c* working into the coal. Broken coal is shown in the bottom of the hole.

51. Cyclone Drilling System.—The rods for the **Cyclone drilling system** are made of extra-heavy black pipe, that is, twice as heavy as ordinary wrought-iron pipe. The pipe rods to which the bit is fastened, and in the case of deep holes to some height above the bit, are made of double extra-heavy wrought-iron pipe. The size of these rods depends on the diameter of the hole to be drilled; for instance, in testing for minerals a 2-inch or 2½-inch diameter casing and 1¼-inch rods will answer for a distance up from the bit, and above them 1-inch rods to the top. In holes having 4-inch casings, the rods are 1¼ inches throughout, and for holes from 4 inches to 6 inches in diameter, 2-inch double-extra pipe should be used.

52. Operation. — The shank of the drill has a hole drilled through its center, and two holes, one from each side of the bit, drilled to intersect the one at the center. On top of the bit, Fig. 45, is placed a shank consisting of a steel washer and a brass or a steel ball *a*, which makes a ball valve when the bit is screwed to the lower section of the hollow drill rod. On the rod at the surface is placed a packing box *b*, which is connected with a hose *c*, from which the rock cuttings pass out of the hollow drill rod. The handle *d* is for revolving the rod in order to obtain a perfectly round hole. The eye *e* is for raising and lowering the drill rods, and is swiveled so that they may be turned; it hangs from a derrick mounted on a portable drilling rig having a bell-crank worked by machinery that gives the power for raising and lowering the drill rods. The rods make from 90 to 120 strokes per minute, and on the down stroke the ball valve opens and permits the chippings to go into the bit and thence into the rod; on the up stroke the ball valve closes and the chippings cannot go back into the hole. Eventually the entire drill rod becomes filled with water and chippings, when it overflows through the hose *c*. Water is necessary for this drilling, and in case the hole is dry it must be poured down the hole. The cuttings when allowed to flow into a tank will show what kind of rock is being cut through and whether it contains valuable mineral. This method drives, drills, and

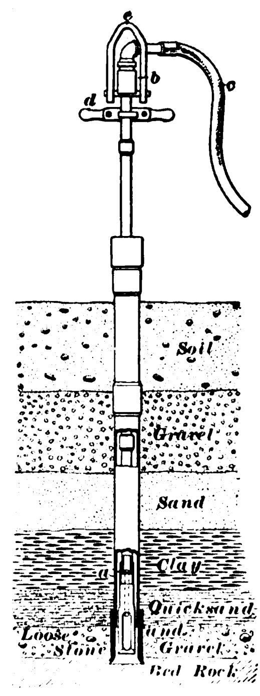


FIG. 45

pumps at the same time, and is said to work excellently. In hard rock free from crevice the casing pipe shown in the figure is not required, but in testing alluvial deposits it is necessary, otherwise, the ground would fall against the drill rods and prevent their churning motion.

HOLLOW DRILL-ROD MACHINES

INTRODUCTION

53. Systems.—There are three systems of rotary boring by pipes that have come into prominence in late years. One is the *Chapman rotary system*, which depends on a bit to do the cutting, with a stream of water to wash the cuttings away. The second is the *Davis calyx rotary borer*, which differs in particulars from the Chapman and has a calyx, or cylindrical-shaped receptacle, for receiving the borings. The word calyx means *cup-shaped*, but the nearest approach to cup in this apparatus is a piece of pipe open at both ends; one end, however, rests on a core barrel, which closes it and forms a receptacle for the borings. This apparatus will furnish a core and cuts rock by means of a rotary motion given to the bit by a torsional strain on the drill rods. The third system, known as the *Diamond drill*, depends on a bit set with diamonds that cut the rock by a rotary motion imparted through the medium of an engine at the surface. All three must have water pumped down their hollow rods to wash away cuttings and keep the bits cool.

DAVIS CALYX DRILL

54. The drill for the Davis calyx rotary borer is shown in Fig. 46. It consists of a cylindrical metal shell about $\frac{3}{16}$ inch thick and 10 or 12 inches long. The teeth on the cutter are alternately set in and out as they would be on a rip saw. The rear of each tooth is beveled to an angle of about 60°, while the front is nearly vertical. The action of this bit is peculiar in that it is worked by torsion, and while it is possible to drill in sandstone and hard shales at the rate of $\frac{3}{4}$ inch per revolution, there are, however, some rocks so hard that these cutters are not advisable, and then are replaced by special bits. Fig. 47 shows this system of core drilling in section. In the figure, *a* is the bit; *b*, the core barrel fastened to the bit; *c*, a reducing plug into which the core barrel is screwed; *d*, a calyx, or an open tube of the same

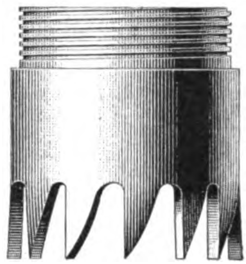


FIG. 46

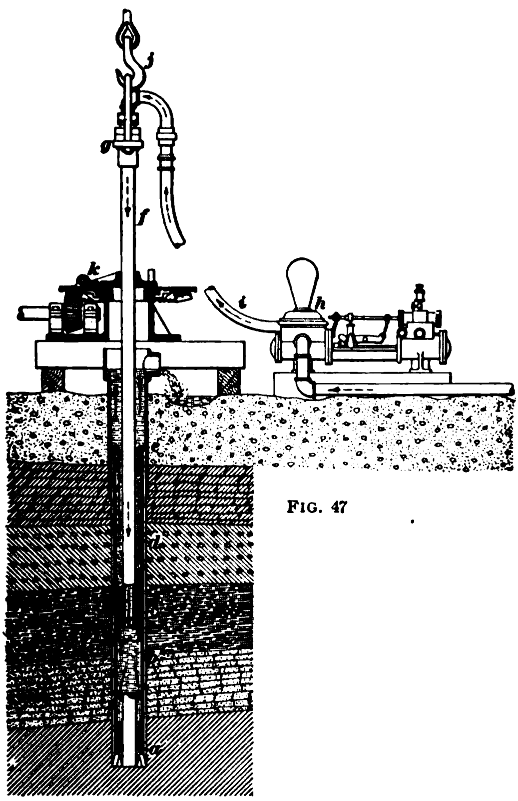


FIG. 47

diameter as the core barrel, resting at the lower end on the reducing plug, leaving its upper end open; *f* are the drill rods, which consist of hollow wrought-iron pipes through which water is forced under pressure to the drill; *g* is a swivel connected with the pump *h* by means of the hose *i*, and through which water enters the drill pipe; *j* is a hook for holding the drill pipe in position, and which also assists in lowering and raising the pipe; *k* is the mechanism by which the drill pipe is rotated. By reference to the arrows, it will be seen that water enters the drill pipe through the hose *i*, passes down the drill pipe into the core barrel, out through the teeth of the bit, and up the sides of the core barrel until it reaches the point *e*. The water passes up between the bore hole and the core barrel very rapidly, but as soon as it reaches the point *e*, its velocity is lessened and the coarse drill borings that are washed up fall into the calyx *d*.

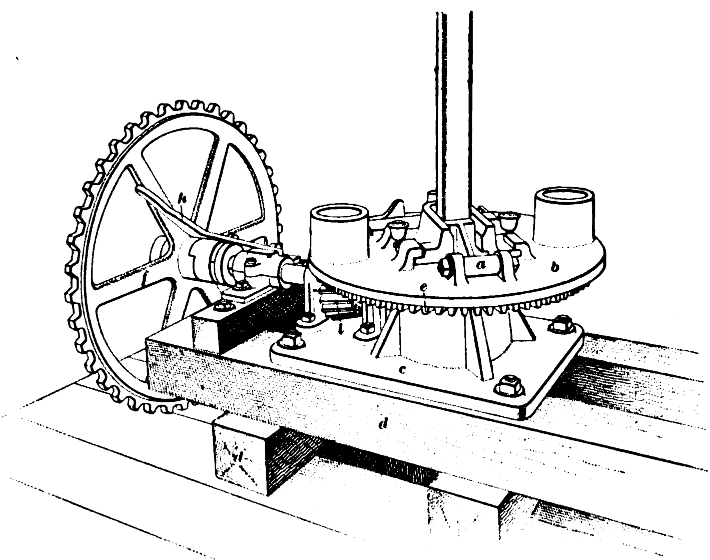


FIG. 48

55. Calyx Rotating Device.—The machine for rotating the drill is shown in Fig. 48, where it will be seen that the drill rod is held in position by the block *a*, which may readily be lifted out when desired. A horizontal table *b* is seen resting on a bedplate *c*, which in turn rests on timbers *d*. Underneath the horizontal table a system of gears *l* are connected and moved by the power wheel *f*. When the gear on the power shaft is thrown into mesh by means of the lever *h*, with the gears under the table the latter revolves and with it the drill rod. This is a very simple device and permits of quick drilling, coupling, and uncoupling the joints.

56. Torsional Boring.—When the apparatus is boring, the pressure of the drill rods thrust the teeth of the bit into the rock and compels them to bite; hence, the bit does not turn until the torsional stress in the tubes is sufficient to overcome the resistance of the rock and start the bit to rotating. Thus it will be seen that the cutter does not begin to act as soon as the drill rods begin to turn; on the contrary, the rods must be twisted considerably before accumulating sufficient energy to overcome the bite, but the moment the strain on the bit exceeds the resistance of the rock, the cutter springs around the groove until it is brought to rest by the opposition of a new bite. When the cutter thus stops, the continued turning of the machine sets up a new partial force that accumulates energy in the drill rods until the rock is again forced to yield, and the cutter is once more turned with rapidity. The fragments of rock as they are broken off by the cutter are carried up between the core barrel and the hole and deposited in the calyx. The object of this calyx is to take care of these grindings; they are not pumped to the surface, nor do they remain in the hole to jam the bit. It is claimed that by this method of drilling, a hole has never yet been lost. The calyx answers also as a sort of a double record, for when the core will not hold together the drill cuttings are saved in the calyx, where with ordinary sludging pumps they are mixed up and deposited at the surface.

57. The Core.—The core drill cuts a groove in the rock and brings up the central portion when not too soft, so that the driller can tell through what character of ground he is drilling. This cutter furnishes a large core, which it will bring to the surface. In case the rock is too hard for the tooth bit, a special bit is used and chilled shot placed in the bottom of the hole. This shot has various sizes and is of such hard material that it will scratch glass. The chilled-shot method of boring has proved quite successful; the makers of the calyx drill say that there is no rock in the earth's crust so hard that it cannot be drilled at a payable rate by this method. There are limitations to the chilled-shot method of boring; for instance, chilled shot will not drill past a rock crevice, for the shot will go into the crack. Should such obstructions be met, the tooth bit takes the place of the shot bit until the crevice has been passed, when the shot bit is substituted for the tooth bit. When drilling with shot the rock grindings are deposited in the calyx without pumping with such force as to wash the shot from beneath the tube, which would be the case if the grindings had to be washed to the surface.

CHAPMAN BORING OUTFIT

58. The **Chapman boring outfit** is somewhat similar to the calyx, but uses as a drill rod a pipe of the same diameter as the hole being bored. It does not save the core, and everything drilled through is washed to the surface. Fig. 49 shows one of the Chapman reversible rotary drilling machines that bores a hole, sinks the pipe, and connects the well casing. The drill rod revolves on ball bearings in the swivel hook *a*. The jaws *b* grip the pipe so as to turn it and at the same time permit it to sink as the hole is deepened. The machine is made reversible for the purpose of connecting the boring pipes quickly, as this is necessary in sinking through quicksand. It can be seen that the grips are on a table provided underneath with a bevel gear-wheel *c*, which meshes with beveled gears *d* on the shaft *e*. This shaft is driven by the sprocket wheel *g*, to which suitable power is attached. Water for washing up the borings enters the

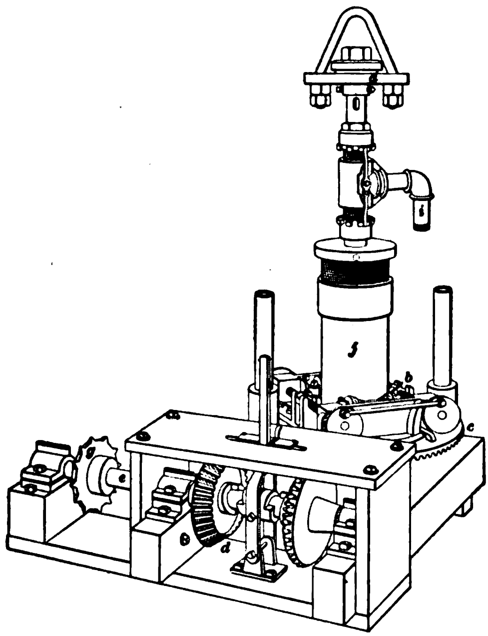


FIG. 49

pipe *i* from a pump and passes down the bore pipe *j*, out under the drill teeth, and thence up the sides of the pipe to the surface. Wells have been sunk by this process of the American Well Works to a depth of 3,067 feet.

In case the drill hole meets rock too hard for the ordinary cutter, a smaller drill with bore rod *a*, Fig. 50, is placed inside the regular bore rod *b*. In the bottom of this hole is placed some very hard material termed *adamantine*, which is moved around by the drill bit *c* until it cuts out a core. While this operation is going on water is passed down through the bore rod in sufficient quantities to wash out the cuttings without washing out the adamantine from under the bit. The bit is frequently raised from the bottom to permit the adamantine to work down to the bottom of the hole, when the weight of the rods holds the material to the surface being cut. The adamantine engages with the object and is carried around with the drill, thus cutting the more brittle rock. When a sufficient core has been cut, the core extractor removes it. This system is sometimes used to recover a string of tools lost by an American percussive oil-well rig.

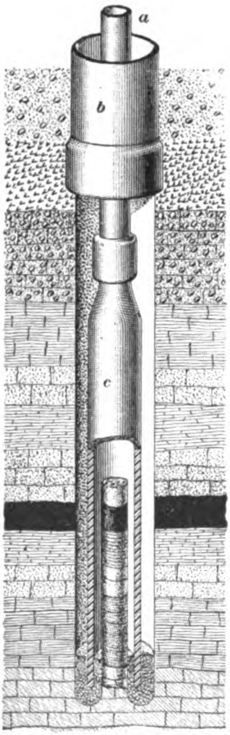


FIG. 50

The rapidity of the work of the Chapman drill depends very largely on the skill of the operator and the good judgment he exercises. It also depends somewhat on the pipe used for sinking the well. Standard wrought-iron, steam, or gas pipe is much better suited for the work than the cheap so-called steel pipe that is put on the market to take the former's place, which it does in many cases, but not for rotary well boring, since it is liable to break off and thereby cause considerable delay in removing the broken section before further work can be done.

There is a great deal of torsion on the boring rods as the well deepens, and as the power is applied on the upper end and the resistance comes on the extreme lower end, if any hard strata are encountered after the hole reaches considerable depth, great care must be taken to prevent the cutting tool at the lower end forcing its way too rapidly into the strata, as the boring rods may not then be able to stand the strain. The weight of the boring rods is adjusted by means of a rope tackle in a derrick above the hole.

There are attachments that connect at the upper end of the boring rods to allow them to turn freely, and swivels are used according to the diameter of the well. Consequently, the larger the hole, the greater must be the water supply, and the larger the water supply, the more hose connections are required. In soft formations, where it is not practical to remove the pipe from the hole after it is once sunk, water must be forced down on the inside of the pipe continually until the pipe reaches the entire depth, since if the water is shut off at any time, the pressure from the different strata is liable to close in around the pipe and prevent its being again moved and also prevent the water's being forced up on the outside. An experimental hole was put down in California to a depth of 1,500 feet in 7 days and 7 nights continual working. In the same vicinity there were several of the American well drilling rigs that had been working for 12 months continually, none of which had been successful in drilling a hole but a trifle over 1,200 feet in depth. In the oil fields at Corsicana, Texas, a number of wells have been sunk with an average of from 900 to 1,200 feet in from 24 to 36 hours. While the Chapman rotary system was not designed for working through hard-rock formations, although considerable hard rock was encountered in the Beaumont field in Texas, drillers have been able to sink through rock which heretofore they did not think the system was capable of boring.

BORING WITH DIAMOND DRILL

INTRODUCTION

59. The first diamond-drill hole in the United States was put down in Northeastern Pennsylvania for the purpose of prospecting for anthracite. Its usefulness was demonstrated to such an extent that it came into general use for prospecting purposes where a rock core of the ground drilled through was desired. The principle of diamond-drill boring is based on the fact that diamonds are the hardest of mineral substances and their abrasive quality when moved over other minerals. If, then, diamonds are set in one end of a cylindrical bit and rotated horizontally, the bit will wear away any other mineral with which it is in contact, and leave a cylindrical core of the mineral, which will protrude upwards inside the bit as the latter sinks into the mineral. The drill shank is lengthened by additional pipe rods so that deep holes may be bored.

60. The Diamond Bit.—One advantage in using the **diamond bit** is that it brings a core of the material passed through to the surface. Fig. 51 shows a core bit having diamonds arranged around the outer and inner periphery of one end of the cylinder so as to cover its entire face area when revolving against rock. The bare bits are made of soft steel, with a thread at one end.

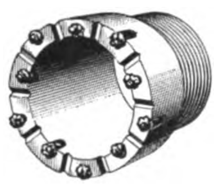


FIG. 51

Two kinds of diamonds—carbonados and borts—are used for diamond-drill work. The *carbonado* is found in opaque nodules of irregular shape, black on the outside, and of various shades of gray when broken. It has no cleavage planes, differing in this respect from the brilliant, and is thus especially fitted for diamond-drill work in hard rock, for the carbons simply wear away gradually without splitting or cleaving. The *bort* is a semitransparent stone, less tough than the gem and has a different crystallization, which makes it apt to split along its cleavage planes. For soft rock borts may be used, but it is customary in medium rock to use both borts and carbonados.

61. Number of Diamonds in Bits.—The number of diamonds required for a bit depends on the hardness of the rock and the diameter of the bit. A bit 2 inches in diameter should not have less than 12 diamonds, and more if the diamonds are of small size. Bits carrying 4 diamonds on the outside and 4 on the inside wear out the metal more on one side than the other, because the drill rods, when lengthened, have a spiral movement, and being rapidly turned strike in the same place with more or less force due to wabbling; this allows the metal to become worn away and thus lessens the quantity holding the diamonds, where if there were more diamonds this would not occur, as has been proved by experiment. With proper setting the actual wear on the diamonds is very little, and the expense from this source is very small. There should be one bit always in reserve.

SETTING DIAMONDS IN THE BIT

62. Tools used for setting diamonds are small chisels, punches, a light hammer, and one or two small drills. The smallest chisels are not over $\frac{1}{16}$ inch in width on the cutting edge. The largest flat chisels are rarely over $\frac{3}{8}$ inch on the cutting edge. The setter first examines the diamonds and determines the best cutting edge and position for each stone. The size and character of the stone somewhat determines the number of diamonds required in a bit. Large bits are frequently set with from 12 to 16 stones and sometimes small bits are set with only 6 stones. The diamonds should be picked out with special attention to their place in the bit and a uniformity of size and weight. This latter point is important, for a small stone set with a number of large ones will become insecure in its setting and necessitate the resetting of the bit long before the other stones require it. As a general rule, four of the strongest stones are picked out for the outside. The bit is placed as shown in Fig. 52 (*a*) and divided, say, into 8 equal parts, which are marked with a punch. Four outside stones are placed in pairs on lines at right angles; four inside stones are also placed in pairs so that they are on lines at right angles. Laid out in this manner and carefully set the bit will be balanced and cannot but run smoothly and true.

After selecting a stone for a certain position, a hole is drilled in the bit with a twist drill smaller than the stone to be set, as shown in Fig. 52 (*c*) at *a*; then by the use of the small chisels and calking tools, the metal of the bit is chipped away to conform as closely as possible to the size and shape of the stone, as shown at *b* and *c*. The stone should set perfectly; that is, it should be up to gauge of the bore hole on the face of the bit as well as on the side. After the cavity has been properly formed, a stone is put

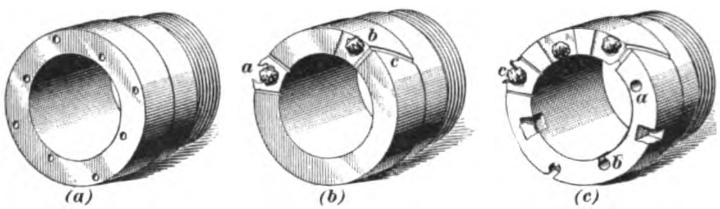


FIG. 52

into place by means of calking tools and punches, and the metal of the bit drawn around the stone, fastening it firmly. Two heavy chisel cuts are usually made a short distance from the stone across the face of the bit, as shown in Fig. 52 (*b*) at *a*, and these are used as starting points from which to draw the metal toward the stone.

In calking the metal, care must be used not to throw the stone out of position, either by crowding it down and to one side or forcing it too high on the cutting face. A little time exercised in this particular when first learning is well spent. The thumb and forefinger hold the calking tools and the little finger, or the fourth finger, holds the diamond in position. While the diamond will stand very heavy steady pressure it is easily shattered if struck with the hammer or by a glance from the calking tool. Care must be taken, therefore, both in setting and in cutting out a diamond from an old bit, not to strike it; probably more diamonds are ruined in this way than by drilling. The metal is next calked evenly all around the diamond; the metal is not to be calked closely on one side and then on the other, but it is to be worked carefully around the stone, thus bringing it together in a body as close as possible. If the stone is so irregular that in order to get it in place in the bit it is necessary to chip away a large amount of metal so that there is not sufficient metal to fill in, a small piece of copper or tough wrought iron can be used for filling in, and thus leave enough metal to permit the stone to be calked into place. When setting the inside stones, it is well to take a small piece of tin or sheet iron and cover the face of the bit and the stones that have been set opposite the stone being worked on. This will often prevent the breakage of a stone through the slipping of a hammer or a tool. A diamond with the face drawn up around it is shown in Fig. 52 (*b*) at *b*.

The proper amount of clearance to give the stones will depend on the character of the rock. For very hard rocks that hold together well, a clearance of $\frac{1}{64}$ inch on each outside stone, making $\frac{1}{32}$ inch for the full diameter, will be found sufficient, but in drilling soft rock, $\frac{1}{32}$ inch, and frequently more, is necessary. After the diamonds are all set, water grooves should be cut across the face of the bit and down the outside, as shown at *c*, Fig. 52 (*b*). These should be large enough so that the drill cuttings can easily be carried away by the flow of water. If the water grooves are not made sufficiently large, the metal of the bit is worn away from the diamonds and the stones become loose and unsafe before they should. The bits should be carefully examined each time the rods are pulled up, and when the metal shows signs of wear, it should be carefully calked back around the diamond. This examination sometimes shows that the diamonds do not cover the cutting face properly. In such cases it is best to set in a small stone, to reenforce the setting for the time being; but when the diamonds are cut out and reset they should be arranged to cover the face being cut. To cut the stones out after the bit has become worn, it is better to take a hack saw or file and cut across the face of the bit close to the stone and drive the metal away from it, than to chip with the chisel until the stone is released. An experienced driller will be able to tell if one of the diamonds comes out of the bit from the jerking motion of the drill rods as they turn.

FISHING FOR LOOSE DIAMONDS

63. In Fig. 53 is shown a *fishing tool* for loose diamonds. This tool goes on to the end of the bore rods or special rods and is lowered into the hole. It has clearance for water, the object of which is to drive sediment away from the bottom of the hole and permit the wax *a* in this bit to reach the diamond and recover it.

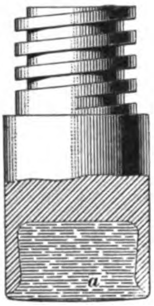


FIG. 53

It frequently happens that diamonds become wrenched from their setting and remain in the hole after the rods are withdrawn. It would be unsafe to continue drilling until these lost stones were removed from the hole, for they would probably wrench other diamonds from the bit and cause a great amount of damage; hence the bottom of the hole must be cleaned out and the diamonds recovered by means of a mass of soap or wax fastened into the end of the rods, which are then let down the hole. The diamonds, together with any other small pieces of rock on the bottom, adhere to this mass and can be drawn out. At times there is a stump core left in the hole, and consequently the above method becomes impracticable. In such a case it may be necessary to use a percussive bit and chop up the stump of the core and the diamonds, after which they are washed out by a current of water, or they may be recovered, as before stated, by means of soap or wax.

DRILLING OPERATION

64. Fig. 54 shows the bottom of a diamond-drill hole in plan and section. The core *C* is formed by the bit cutting out the annular space *A S*. In order to bring this core to the surface, some device must be provided for breaking it off at the bottom and for holding it in the tubes while it is being hoisted. The core is broken and held by a *core lifter*, Fig. 55, which consists of a ring so constructed that it will grip the core near its base whenever the rods are raised. The core lifter fits into a tube, Fig. 56, termed a

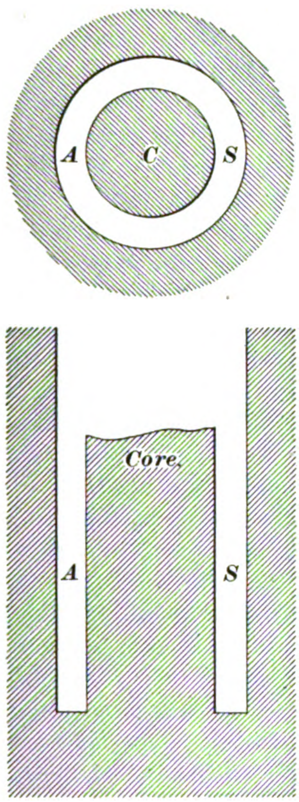


Fig. 54

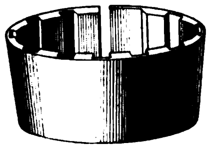


Fig. 55

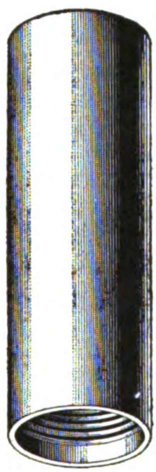


Fig. 56

core shell, so grooved that while it allows the core lifter to go down over the core it will not permit its being raised, unless it brings the core with it.

65. Fig. 57 is a vertical section through a diamond-drill hole. The stand pipe *n*, which is provided with a shoe *o*, is driven into the ground until it reaches bed rock, for the

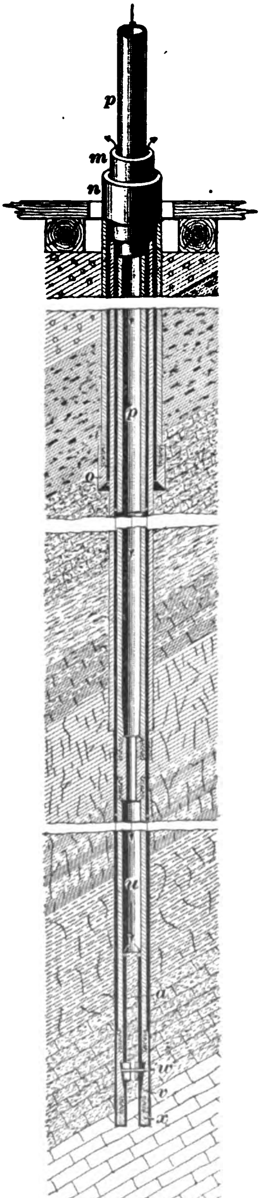


FIG. 57

purpose of protecting the drill hole. The casing *m* is put down through the upper formations, which tend to clog the hole or carry off the water used in drilling. The drill rods *p*, which transmit power to the bit, are connected to the core barrel *u*, which in turn is connected to the core-lifter shell. The bit *x* is screwed on the lower end of this shell. The water that is forced down through the center of the drill rods *p* passes under the bit and carries the cuttings up through the annular space between the rods and the hole, or the rods and the casing, as indicated by the arrows. When the rods are lifted from the hole, the core-lifter ring *w*, which is always in contact with the core, slides down into the tapered recess in the core-lifter shell *v*, and bites or grips the core so as to break it off and retain it in the core barrel.

The drill rods are simply pieces of extra heavy pipe, and are joined together by inside couplings, which give a smooth external surface, and are ordinarily in lengths of from 5 to 10 feet each. Where deep drilling is to be done the increased cost of short rods due to couplings and weight makes it economical to use special drill rods from 20 to 30 feet long. The drill rods are always uncoupled in sections as long as the derrick will handle.

66. Pulling Up Rods and Pipe.—For hoisting the rods a simple tripod made from three sticks of timber 20 to 30 feet long, joined at the top, and having a hoisting block swung from the joint will answer unless the hole is to be very deep, when some more elaborate structure, such as the special steel tripod, shown in Fig. 58, or a wooden derrick, may be used.

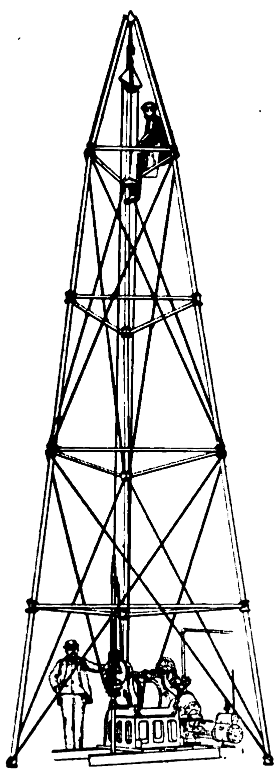


FIG. 58

When it is desired to pull up an old casing or stand pipe, it can sometimes be done by means of an ordinary hoisting drum and rope; in other cases, it becomes necessary to put clamps on the casing and use jack-screws to pull it from the ground. By using sufficiently heavy screws, it is possible to exert a force that will part the casing or stand pipe if it is too firmly embedded in the material, and then only a portion of the tube would be recovered. When the drill rods must be raised for the extraction of the core or the renewal of the bit, the hoisting plug, shown in Fig. 59, is screwed on the end of the rods.

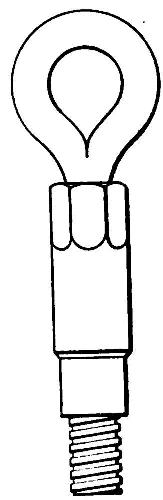


FIG. 59

67. The Differential Feed.—That the diamond bit may cut properly, it should not be forced against the rock with too great pressure while it is being fed forwards, for this reason the machine that operates the drill rods must be provided with some form of feed mechanism.

In the **differential feed**, the upper length of rods is provided with strong square threads and passed through a nut that is rotated in the same direction as the rods, but not quite so rapidly, thereby causing a differential movement. To understand the principle of the differential movement, suppose the nut was held stationary, and that the rod and nut have each 2 threads to the inch, then for every two revolutions of the rod the bit would advance 1 inch, which is altogether too much cutting for the diamonds to do in two revolutions of the drill. Now, suppose again that the nut makes, say, 59 revolutions while the rod makes 60; the bit will advance only $\frac{60 - 59}{2} = \frac{1}{2}$ inch, or $\frac{1}{2 \times 60} = \frac{1}{120}$ inch for each revolution of the rod. Thus it is seen that a very small advance per revolution of the bit can be obtained by the above principle, and yet strong threads can be used to support the entire length of drill rods.

If the differential feed were not provided with some means of release, it would produce an enormous pressure whenever the bit encountered a hard formation. For this reason the feed mechanism is driven by an adjustable friction device that allows the driving mechanism to slip with reference to the feed mechanism whenever the pressure on the bit becomes too great. This slipping has the effect of giving the bit a finer feed in hard rock. Most machines provided with differential feeds have several sets of gears, by means of which the feeds can be varied without having to depend on the slip of the friction device to produce finer feeds, this being intended only as a safety device.

68. Pressure Indicators.—In order to show the pressure on the bit, some machines are provided with **thrust indicators**, so constructed that the thrust of the rods is received by the piston working against some liquid (usually glycerine), and the pressure on the liquid is shown by means of a gauge.

If the pressure on the bit rises, the gauge shows the driller that the bit has encountered a hard formation, and he reduces the feed by throwing in a different pair of gears or by changing the adjustment of the friction device through which the feed is driven.

69. The Hydraulic Feed.—In the **hydraulic feed**, the pressure on the bit is produced by water acting on a piston in a vertical cylinder, and it is possible to observe at any instant the pressure on the bit by means of a gauge on the cylinder. Consequently the driller can regulate the advance of the bit to the very best advantage. For instance, if the rock is hard the bit will advance slowly and the pressure in the cylinder rise, while if the rock is soft the bit will advance rapidly and the pressure in the cylinder fall. In the former case the driller lessens the supply of water, and in the latter case he increases it, keeping the proper pressure on the piston and rods.

The water below the piston prevents the bit from sudden and rapid advance in case it is passing through a crevice or soft place in the rock, and in this way greatly protects the diamonds from sudden shock and possible displacement.

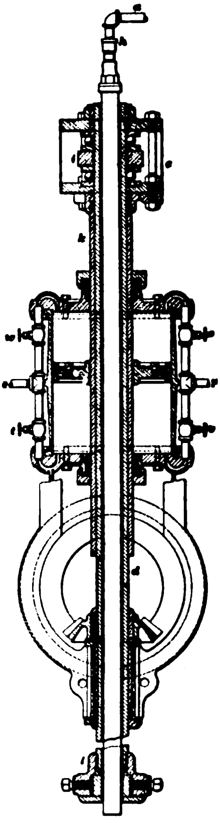


FIG. 60

Fig. 60 shows a longitudinal section of an hydraulic-feed mechanism, in which the water passages and the functions of the valves can be seen. The drive rod *d* is connected to the drill rods by the chuck or clamp *l*, and rotates within the hollow piston rod *k*, being supported by the ball-bearing collar *i* within the case *c*. Water is forced into the drill rods through the pipe *a* and the swivel *h*. In order to increase the pressure on the bit, it is necessary to open valve *s* wider or close *w* somewhat, while at the same time *v* may be closed a little and *t* slightly opened. If, however, there is too much pressure upon the bit, the operation is reversed; the water passes into the cylinder through *r* and out through the valve *e*.

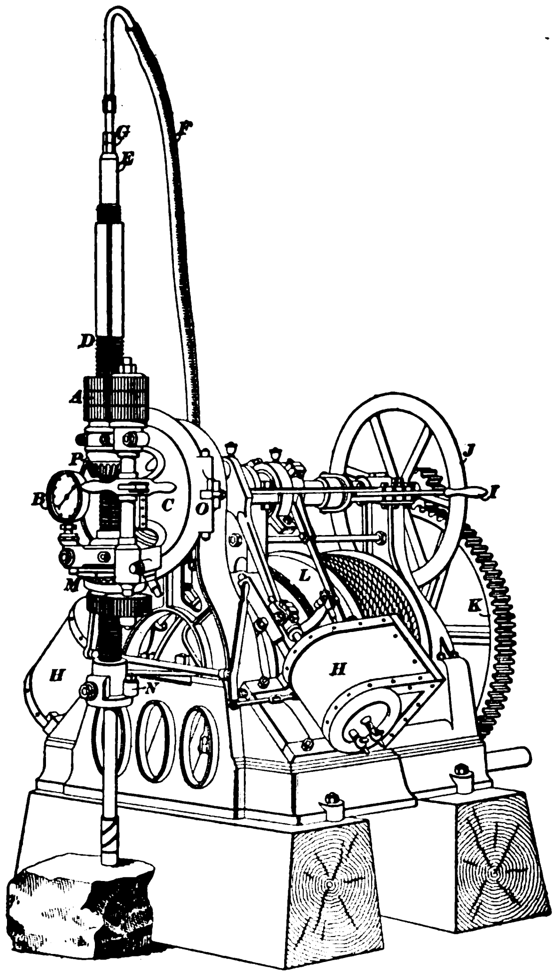


FIG. 61

70. Fig. 61 shows a diamond drilling machine having an engine with two cylinders *H*, *H* on opposite sides of the engine frame. This engine may be reversed by means of the reverse lever *I*. The large gear *K* is used to drive the hoisting drum *L*, but it may be driven at different speeds by means of a series of change gears, not shown in the figure. The hand wheel *J* is used to turn the engine shaft and gearing when it is desired to throw in a different series of gears for the operation of the hoisting drum. The feed can be changed by means of the handle *C*, which throws in any series of the gears *A* or throws them all out. The roller bearing *M* receives the thrust, and is so arranged that it registers thrust in either direction by means of the thrust gauge *B*. The chuck *N* at the bottom of the feed-screw *D* holds the drill rods and drives them. The swivel *G* connects the water-supply pipe *F* to the drill rods *E*.

There is a thread on the upper end of the feed-screw *D*, so that another chuck can be placed on that end of the feed-screw; or the chuck *N* may be placed at the upper end of the feed-screw when drilling upwardly inclined holes. This drill is provided with a swinging head. There is a latch bolt *O*, which can be loosened, and on the opposite side of the head there is a similarly constructed hinge. By means of this device the feed mechanism, driven by means of a pair of bevel gears *P*, can be swung from over the hole. When the mechanism is swung from over the hole, the drilling mechanism is thrown out of gear, so that the engine may be used to operate the hoisting drum *L* for removing the rods from the holes.

71. Double-Cylinder Hydraulic Feed.—Fig. 62 illustrates another form of machine, which has a capacity for drilling to a depth of about 2,000 feet. It is provided with a **double-cylinder hydraulic feed** and has a fixed head, making it necessary to remove the machine from over the hole for changing the rods; this necessitates some form of flexible or telescopic joint in the steam and exhaust pipes. This is accomplished by means of a bracket *C*, which holds the steam pipe *A* and the exhaust pipe *B*, so that as the drill is moved backwards or forwards, the pipes connected with the engines work in and out through the stuffingboxes shown in the illustration. The gearing for changing the speed of the hoisting drum *D* can be seen at the back of the machine. When the large gear *E* on the shaft carrying the hoisting drum is geared with the small pinion *F* on the engine shaft the drum will be driven rapidly; on the other hand, if the gear *F* is brought into

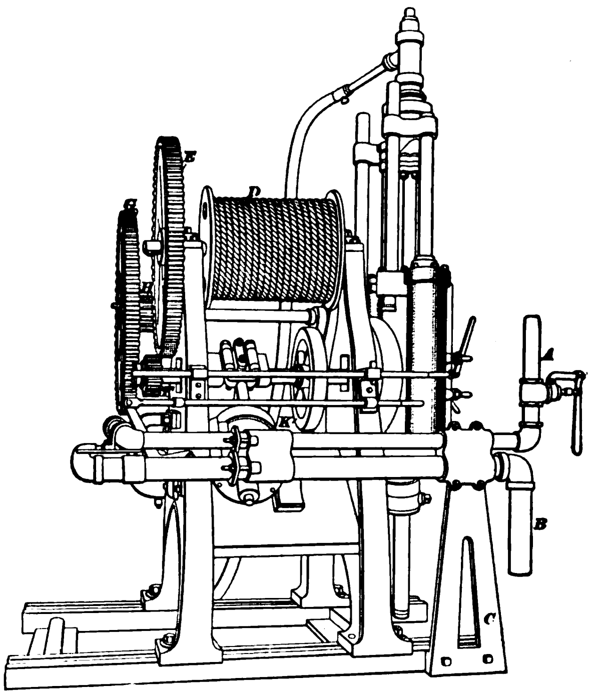


FIG. 62

mesh with the gear *G*, and the pinion *H* into mesh with the gear *E*, the drum will be driven slowly. When the drum is driven more slowly by the same engine, it has greater lifting power. The small hand wheel *K* is used in turning the engine shaft so as to bring the gears into mesh. The different combinations of gearing cannot be changed while the machine is running.

72. Portable Drills. — Small **portable drills** with engine, pump, and drum are mounted on wheels for transportation. These machines are useful when it is desired to drill a large number of comparatively shallow holes in the same locality for testing the extent of a deposit.

Diamond-drill-machine makers have a number of different styles of portable drilling machines from which to choose, and since they are continually adding minor improvements, and the machines do not in themselves differ from those described, their description is omitted.

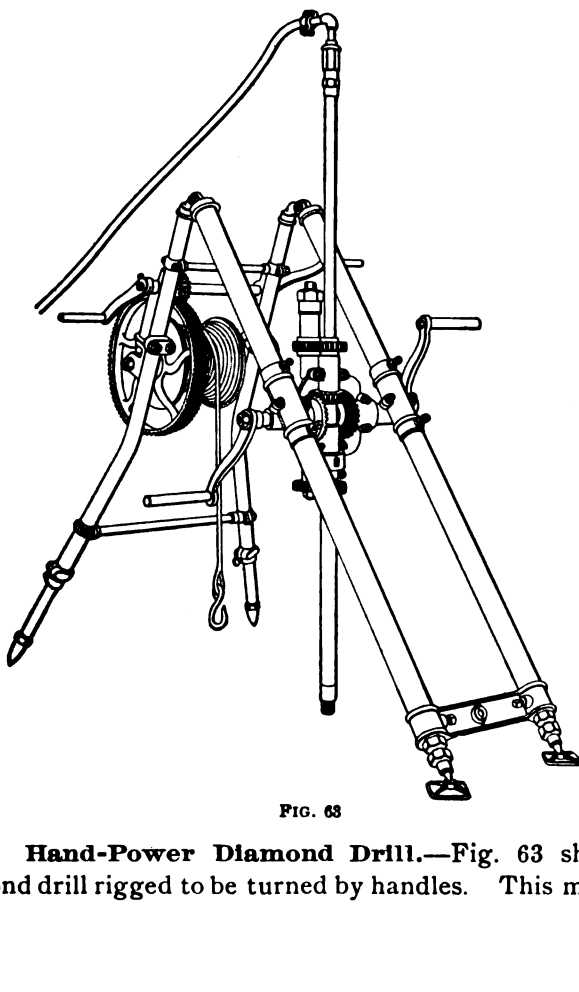


FIG. 63

73. Hand-Power Diamond Drill.—Fig. 63 shows a diamond drill rigged to be turned by handles. This machine may be adjusted so as to drill at an angle, and if power is handy the handles may be removed and a pully substituted. Power driving is in every way more economical and satisfactory for such work, even when above ground and in soft formations. The machine shown is apt to kick back when boring at an angle unless the legs are heavily weighted. To remove the drill from the hole, the setscrews on the legs are loosened and the lower collars slipped down the legs, taking the machine with them; the upper collars are left in place, so that the machine can be centered over the hole when drilling is resumed. Water may be fed to the drill from a tank or a hand force pump, as is most convenient.

74. Electric Diamond Drill.—The increasing employment of electricity in mining operations has opened a new field for the diamond drill. One of the difficulties heretofore in the way of diamond-drill prospecting in rough, mountainous localities, has been the lack of suitable power for the machine, as the nature of the surface of the country at times makes it impracticable to get heavy boilers and machinery close to the ground to be prospected. Even where this could be done, there remained the difficulty and expense of transporting fuel to the boilers, if the mine opening was located, as often happens, on a steep declivity where timber was scarce. In case prospecting was to be carried on underground, a further difficulty would arise where compressed air was not used as a motive power, from the fact that steam underground is unsatisfactory for power and uncomfortable for the men; besides, it is liable to be a source of expense, owing to the damage exhaust steam causes to the mine timber.

To overcome these objections, **electric diamond drills** have been designed, which will permit core drilling to be carried on in places where it has hitherto been impracticable. The dynamo can be located near an engine or waterwheel at any distance and the power carried easily to the drill, which can be situated on the mountain top, in a deep shaft, or in any part of the mine.

Numerous styles of electric diamond drills have been devised, differing chiefly in the arrangement of the dynamo,

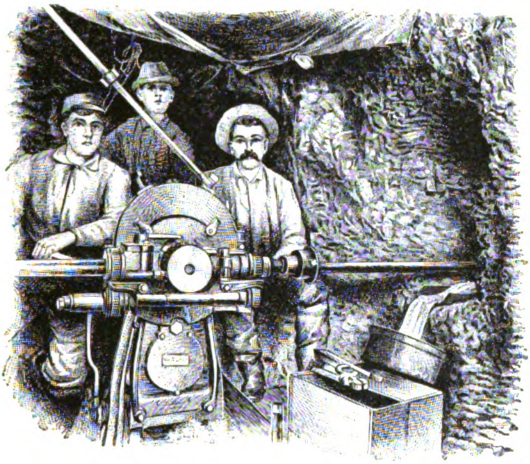


FIG. 64

the drilling machine proper being similar to those mentioned. Fig. 64 shows a diamond prospective core drill at work in the Smuggler Mine, Aspen, Colorado.

PRACTICAL NOTES ON DIAMOND DRILLING

75. Preparation for Surface Drilling. — Having selected the location of the required hole, arrangements must be made for an ample supply of water for the use of the drill and the boiler. Next, the stand pipe must be sunk to bed rock. In the case of fine sand or very soft material, such as occurs in swamps, the stand pipe may be driven to bed rock without any trouble, and a jet of water may be introduced to flush out the material as the pipe is driven down. In the majority of cases, the drift contains a greater or less number of boulders, which interfere with sinking the pipe.

Where the drift does not exceed 15 feet, it may be best to excavate to bed rock and carefully plumb and secure the stand pipe, the excavation then being filled and the drill placed in position. If the drift material is thick, and especially when it contains large quantities of quicksand or water, which would render excavating difficult, it is necessary to drive the stand pipe. If boulders are encountered they are drilled into and blasted; a hole of sufficient size to allow the introduction of the stand pipe may be drilled through a very large boulder. This drilling is usually accomplished with a percussive bit fastened to the end of the ordinary diamond-drill rods, or to rods somewhat heavier especially provided for this purpose.

At times it will be found more expeditious to use a portable American well-drilling rig and tools for sinking the stand pipe. In case the stand pipe should break while being forced through ground containing boulders, it will be necessary to pull it up and begin again. The stand pipe must be tightly jointed into the bed rock to prevent the loose material going into the hole, or the water used for drilling going out at the joint. Special rigs are furnished with diamond drills, by means of which stand pipes may be put down through ordinary drift material. These consist of pod bits, auger bits, percussive bits, casing bits, etc. In many cases it is quicker to put the stand pipe down with the rig provided with the drill than it would be to employ a special rig of any other type.

76. Drilling Pit.—Where it is desired to drill fan holes, that is, several downwardly inclined holes from the same point, it may be well to sink a small pit and locate the drilling machine on the bed rock. The advantages of this method are: (1) No stand pipes are required for the several holes. (2) Flatter holes can be drilled than would be the case were the drill placed on the surface; this applies to cases where the drift material is 20 feet thick or more. (3) There is no delay between the drilling of successive holes; that is, after one hole is drilled there is no waiting for the next stand pipe to be driven.

The disadvantages are: (1) Even if the shaft or pit were dry, a pump will be required to remove the water from the pit, because the drill water is present if the pit itself is dry. (2) When operating at the bottom of a pit, there is not sufficient space for quickly handling the drill rods. (3) If the drill is driven by steam, the boiler being on the surface, will require the steam to be carried some distance.

77. Drilling.—After drilling is commenced it is continued night and day until the work is finished. The work is carried on in two shifts of 12 hours each. If the hole is comparatively shallow, not over 700 feet, and the formation not extra hard, four men comprise the drilling crew, the head driller acting as foreman during the daytime and setting bits while the machine is running. He has an assistant who acts as fireman. At night the assistant foreman runs the drill with the aid of his fireman.

While drawing the rods from the hole one of the men goes on top of the shanty, or up into the derrick, the other remaining at the collar of the hole.

In case the hole is deep or the material very difficult to drill through, five men comprise the drilling crew, there being two foremen, two firemen, and a chief driller. In this case the chief driller sets the bits and has general oversight of the work. One of the foremen and his fireman operate the drill at night, and the other two during the day.

Many large mining companies that have a number of drills in operation keep a man employed setting bits for them, in which case each drilling crew is comprised of four men.

78. Casing.—The stand pipe is of larger diameter than the drill rods, so that if it is desired to use a casing pipe, it can be put down through the stand pipe. One advantage of a casing is that the drill rods fit more closely than they do the stand pipe, and hence the hole will be started more accurately; that is, the tendency to drift out of the vertical on the start will be reduced.

After the hole has passed through a portion of the rock, it may encounter loose material, which must be kept out of the hole, and this requires that the casing be continued through the troublesome formation. To accomplish this, any casing in the hole is pulled up and a reamer introduced, which enlarges the hole down to and through the bad ground. The casing is then introduced and keeps the hole free from the troublesome material, while the work proceeds as before. To avoid reaming, a smaller casing may be introduced inside of the diamond-drill hole, the work from this point on being continued with a smaller bit than that with which the first portion of the hole was drilled. At other times expanding bits are used to cut the rock away from underneath the casing, and thus allow it to follow the bit down.

79. Changes in the Machine Speed.—In case the machine increases in speed when drilling it is a sign that either the bit has cut into a softer formation, thus reducing the work and allowing the machine to speed up, or the drill rods have twisted off. In case the latter has occurred, the flow of wash water will be very much increased, and the pump will have a tendency to race.

In case the machine slows down, the drill has either cut into a harder formation, thus throwing more work upon the bit and the engines, or the core has blocked or wedged in the core barrel and is being ground to powder, in place of feeding up into the barrel as it should. The driller's experience will usually tell him which of the two has occurred. In case the core has wedged in the core barrel, it may cut off the flow of the wash water, thus causing the pump to labor. At times this wedging or blocking of the core may free itself in a few moments and the work continue as usual, while in other cases it is necessary to pull up and inspect the condition of the bit and core barrel. If the driller's experience has shown him that the bit should drill a certain distance in ordinary formation before it becomes dull, and this slowing down comes after it has drilled but a small fraction of that distance, it is very good evidence that the core barrel has become blocked.

80. Side Friction.—At times, gravel, sand, or bits of rock from the formation passed through get into the hole and block the rods. If, upon lowering the rods into the hole while they are still suspended (that is, with the bit off the bottom), they rotate with difficulty and in a jerky manner, it is evident that such obstructions are present, and they must be removed either by casing the hole through the troublesome formation or by flushing out the portion then in the hole and seeing if any more accumulate. At times, this **side friction** is caused by the sliding of loose or shaly rock against the rods; under such circumstances the hole requires casing.

81. Washings. — The **washings** brought up by the water are not all bit cuttings, for while passing through soft formations the rods wear more or less material from the sides of the hole. Any change in the character of the wash indicates that the drill has passed into a different formation.

Sometimes tests are made to see how long it takes the water to pass down the rods and return. This is accomplished by circulating candle grease or coloring matter through the pipe and hole.

82. Parting of the Rods. — The drill rods may be parted by breaking; by the thread in a coupling becoming stripped; by a coupling unscrewing while the rods are being raised or lowered; or by the safety jack that holds the rods at the surface during the process of raising or lowering giving way at such times as the hoisting gear is uncoupled from them.

If the rods drop when they part, the diamonds are liable to be smashed.

The lower portion of the diamond-drill hole usually contains more or less mud, and if lost rods are allowed to remain in this mud, it may set like a cement, and render their recovery almost impossible.

83. Reaming.—Fig. 65 illustrates a reaming bit with a bevel face *A*, on which the diamonds are set. A few stones are also set around the periphery of the portion *C*, in order to maintain the diameter of the hole being reamed. A coupling that screws into the lower end of the bit is shown at *B*; to this one length of drill rod is screwed. The

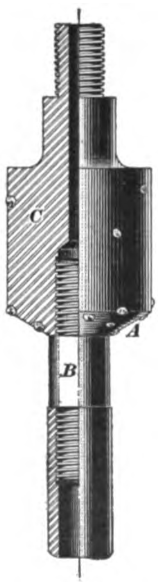


FIG. 65

FIG. 66

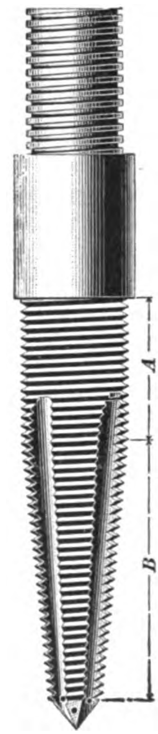


FIG. 67

drill rod acts as a guide and keeps the reaming bit in line with the hole previously bored. The upper end of the bit is so formed as to screw into the drill rods above in place of the coupling.

Fig. 66 shows a fishing tap with the thread tapered throughout its entire length and flutes extended to the shoulder. The hole through which the water passes extends to the point of the tap. The end of the tap has teeth cut in it like a rose bit. This tap is very useful where the weight of the parts to be removed are not too great, but being tapered throughout its entire length it has a tendency to spread the piece into which it is screwed and hence to pull out rather than to lift the lost rods. Fig. 67 illustrates a tap constructed on a slightly different principle. In this case the point of the tap is formed like a drill and point reamer, and is intended for cutting its way into or through the jammed end of the rods. The hole for the water stops an inch or so from the tap, and from this point small holes are drilled from the flutes or between the teeth at the end of the tap into the main supply passage. Thus the water or other lubricant used during the fishing is furnished to the cutting edges as required. The portion *B* of the tap is tapered, while the portion *A* is straight. The result is that when a tap is secured nearly up to the shoulder it will form threads on the rods for a distance equal to the straight portion *A*, and hence the tap is not as liable to pull out as if it were tapered throughout its entire length.

Fishing taps are best adapted for screwing into couplings, because the metal of the coupling is thicker than that of the tubes, and while a tap might take a firm hold in the coupling, it would be liable to pull out from the tubes. On this account it is sometimes necessary to send down special tools and cut off all the tube above the upper coupling, and then screw the tap into this coupling and draw out the lost rods. At times fishing dies are used, which are screwed over the outside of a coupling, thus enabling it to be drawn from the hole.

84. Recovering Lost Bits. — Figs. 68, 69, 70, and 71 illustrate a method sometimes employed to recover a lost bit. It will be seen that the upper end of the bit *A* has become so jammed to one side that it is impossible for a fishing tap to catch hold of it. In such a case as this, it would be necessary either to abandon the hole or to drill down around the bit. Fig. 68 shows the original hole of the diameter *B* with the bit *A* at its bottom. Fig. 69 shows

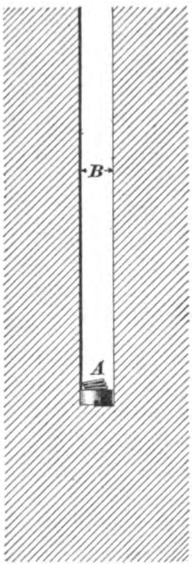


FIG. 68

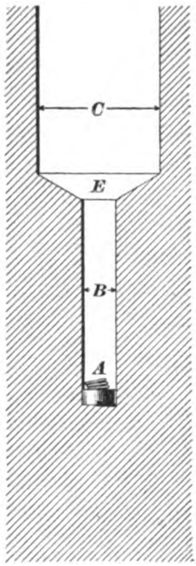


FIG. 69

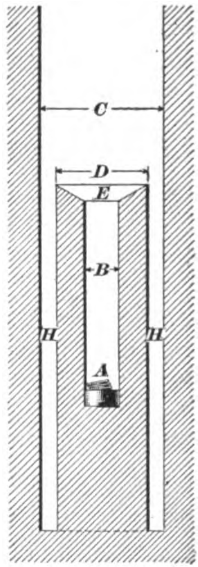


FIG. 70

the hole after it had been reamed to the size *C* down to the point *E*, where a casing bit has been introduced and the annular space *H H* shown in Fig. 70 drilled down about the old hole. The core shown in Fig. 71 is then drawn up in the ordinary manner. It will be seen that this core contains the lower end of the old hole, with the lost bit at the bottom.

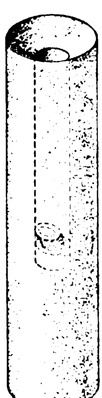


FIG. 71

After the lost bit has been recovered, the hole can be continued by using a larger bit or starting a small bit and using some device to keep the rods central in the hole. If this precaution is not taken, the hole may deflect rapidly from the perpendicular.

If the rods have simply become unscrewed, it may be possible, by a little careful work, to screw them together once more and draw them out without the use of any special tools.

85. Wooden Fishing Taps.—Sometimes lost rods may be recovered by using a block of dry, hard wood in place of a fishing tap. The wood *A*, Fig. 72, is screwed into the end of a rod *B*. The rod is then lowered down the hole and the wood driven into the upper end of the lost rods, as shown in Fig. 73, and water poured down through the rod *A* to swell the plug; the two rods are then drawn out together. This method is very useful in recovering core barrels, bits, or short pieces of rods; the rod *A* does not turn while making the coupling. Sometimes the bit or core barrel may rotate with the fishing tap and render it impossible for the tap to obtain a sufficient hold on the lost piece to bring it out.

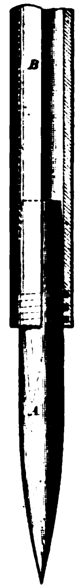


FIG. 72

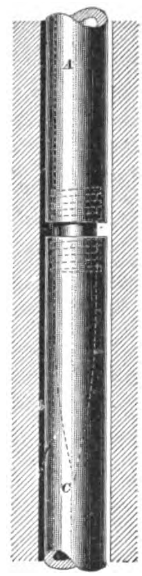


FIG. 73

Should a diamond drill hole contain so much water that the plug would swell before it could be driven into the lost rods, that portion of the wood projecting from the rod can be given a coat of paint, and after the wood has been driven into the lower rod water is poured into the upper rod. This acts upon the unpainted end grain of the wood exposed in the tube, swelling the block and connecting the rods as desired.

When the lost rods become firmly wedged in the hole, it may be necessary to unscrew them by means of a left-hand fishing tap; in this case it is necessary to pin all the joints of the rods used to operate them, unless these rods are also provided with left-hand threads.

DRILLING RECORDS

86. Object of Drilling Records.—In diamond drilling, accurate records of the drilling should be kept. In average drill work it is difficult to obtain a core of more than 90 per cent. of the distance drilled. At the same time there ought to be no trouble in determining the thickness of any rock stratum to within a fraction of an inch, providing it does not exceed a thickness of 5 feet. The drill runner should at every change in the drilling make a measurement and note the depth in his notebook for comparison with the core.

The chief driller should keep a record of all these measurements and points of interest in regard to the core. The supposed or known drift of the drill hole should be recorded by the engineer in charge of the surveying. The core should be saved and arranged in its proper order in boxes provided with parallel grooves. These grooves may be made by simply nailing thin strips of wood in the bottom of the boxes in such a manner as to form narrow divisions. The depth should be recorded upon the core by labels and blocks on which the depths have been recorded inserted in the boxes between core sections.

87. Accuracy and Speed.—In the case of shallow holes drilled to determine the thickness of a known formation, such as a deposit of iron ore, salt, or gypsum, it may be policy to push the work rapidly, as small discrepancies, caused either by drift or by the loss of portions of the core, are not of much importance, but when drilling deep holes for more valuable material, it is important that the record of the formation passed through should be accurate; for this reason, it may be necessary to spend a great deal of time on the drilling.

When the pressure gauge or the behavior of the machine shows that the bit has cut into a different formation, it may be advisable to pull up the rods and investigate the condition of both the core and bit before proceeding. This is of especial importance when prospecting for the precious metals.

It is important that the bit should rest on the bottom of the hole when drilling is commenced, otherwise time will be wasted while the machine is feeding the rods forwards to reach the bottom of the hole or the rods may be dropped and the diamonds smashed. It is also important that the bit be carefully let down to the bottom of the hole, for if it were dropped the diamonds might be smashed.

It is necessary that every portion of the apparatus be in perfect repair, and that the men in charge of the work use their utmost skill and caution in each operation, for if the men are not careful accidents will happen to retard the work, and possibly cause the loss of the hole. No one without considerable experience should attempt a deep diamond-drill hole.

There is no class of work in which the old adage, "The more hurry the less speed," applies more fully than to diamond drilling, for when the men get in a hurry they are liable to drop rods, lose diamonds, let the hole run out of true, and do a number of similar things, all of which will result in a greater or less delay in the work.

88. Size of the Hole.—As a general rule, it is best to use the smallest bit that can be conveniently handled, for a small bit means less cutting, less expense for diamonds, and greater speed in the work. For holes from 500 to 600 feet deep, bits of from $1\frac{3}{8}$ inches to $1\frac{1}{4}$ inches outside diameter are used. These will take out a core of from $\frac{15}{16}$ inch to 1 inch diameter.

89. The Influence of the Drill-Hole Angle.—Vertical holes give less trouble than those which are started at an angle; for in the case of a vertical hole, the rods do not lie upon the bottom of the hole, and hence the drilling machine does not have to overcome great friction in addition to the work of driving the bit. It is much easier to keep a vertical hole straight than a horizontal or an inclined hole, for the wear upon the core barrel and rods is very much less, and, as a consequence, it is easier to guide the bit than in the case of an inclined hole, for the rods immediately back of the bit can more easily be kept the full size. It is much easier to handle and change the rods in the case of a vertical hole than when drilling at an angle.

90. Rate of Drilling.—The **rate of drilling** depends on the depth of the hole, the character of the rock, the size of the drill, and the power being used. It is rare that small drills used for prospecting to a depth of 700 feet about mines succeed in drilling more than an average of 8 feet per shift throughout the year, and yet some phenomenal records have been made for a short time—such, for instance, as the taking out of over 60 feet of core in 24 hours, or the boring at the rate of 30 to 40 feet an hour for a short time in comparatively soft material. This rapid boring is not always advisable, for reasons already stated.

91. Cost of Drilling.—Several tables are here given to show the **cost of diamond drilling** in various formations, and it will be seen that these costs vary from less than $1 to over $5 per foot.

TABLE III

RECORDS OF COST PER FOOT IN DIAMOND DRILLING

	A	*B*	*C*	*D*	*E*	*F*	*G*	*H*
Labor	.707	1.040	2.483	1.150	.581	1.615	1.030	1.720
Fuel	.094	.270	.256	.019	.000	.216	.090	.214
Camp account	.373	.559	.789	.538	.295	.621	.384	.549
Repairs	.139	.110	.294	.171	.135	.144	.103	.185
Supplies	.034	.065	.039	.074	.023	.032	.011	.039
Carbon	.263	.658	.859	.860	.843	1.587	.934	.684
Superintendence	.239	.322	.628	.040	.063	.192	.140	.305
Total	1.849	3.024	5.348	2.852	1.940	4.407	2.692	3.696

NOTE.—*A*, 5 holes, 1,066 feet, sandstone and marble; *B*, 1 hole, 1,293 feet, black slate and jasper; *C*, 3 holes, 478 feet, jasper, very hard; *D*, 5 holes, 780 feet, jasper, hard; *E*, 1 hole, 216 feet, iron slates; *F*, 1 hole, 174 feet, jasper and slate; *G*, 2 holes, 267 feet, jasper and slate; *H*, 3 holes, 410 feet, jasper.

92. The cost of boring 2,084 feet of hole in prospecting the ground through which the Croton aqueduct tunnel was to pass is given as follows: 814 feet of soft rock (decomposed gneiss) was drilled at a cost of $1.15 per foot, at a daily rate of 23.1 feet; 347 feet of hard rock (gneiss) was drilled at a cost of $3.97 per foot, at a daily rate of 11.1 feet; 923 feet of clay, gravel, and boulders was drilled at a cost of $4.07 per foot, at a daily rate of from 6½ to 9 feet. The average daily progress in drilling the entire 2,084 feet was 10.2 feet.

In the Minnesota Iron Company's mines at Soudan, Minnesota, the diamond drill is used for drilling holes from 10 to 40 feet in depth in the back of the stopes, practically all the work being done in iron ore. The average cost per foot of drilling 13,512 feet of hole was $.7703, which was divided as follows:

Carbons	$.3400
Supplies, oil, etc	.0700
Fuel	.0400
Repairs	.0500
Labor	.2703
Total	$.7703

The following tables give the cost of boring at two Michigan mines:

TABLE IV

					Total Cost	Cost Per Foot
Labor	400¼ days setter	at $3.00	$1,200.75		$2,506.10	$.669
	372 days runner	at 2.25	837.00			
	230½ days runner	at 2.00	460.50			
	4½ days laborer	at 1.75	7.85			
Carbon, 68⅜ carats, at $15.144					$1,035.47	.276
Bits, lifters, shells, barrels, and repairs					433.81	.115
Oil, candles, waste, and supplies					128.09	.035
Estimated cost compressed air					374.60	.100
Total					$4,478.07	$1.195

Number of holes drilled	28
Drilled in hematite	193 feet
Drilled in jasper	646 feet
Drilled in mixed ore	986 feet
Drilled in dioritic schist	1,921 feet
Total drilling	3,746 feet
Number of 10-hour shifts drill was running, including moving and setting up	603.0
Amount of drilling per 10-hour shift	6.2 feet

TABLE V

Underground drilling	6,075 feet
Surface drilling	1,414 feet
Stand pipe sunk	470 feet
Total distance run	7,959 feet
Actual drilling time underground	672 shifts
Actual drilling time on surface	165 shifts
Time of foremen, setter, moving, and stand piping	1,314 shifts
Total time worked	2,151 shifts
Average progress per man per shift	3.70 feet
Average progress per drill per shift actually running	8.95 feet
Weight of carbon consumed	111 carats
Distance drilled per carat of carbon consumed	67.38 feet

	Amount	Per Foot
Cost of carbon	$1,887.00	$.237
Cost of supplies and oils	134.13	.017
Cost of fuel	360.73	.045
Cost of shop material, etc	663.36	.083
Pay roll	4,000.03	.502
Total cost	$7,045.25	$.884

SPECIAL METHODS FOR DRILLING IN SOFT OR SOLUBLE MATERIALS

93. Methods Adapted to Soluble Materials.—When drilling through soluble materials, such as salt formations, with a diamond drill, the core would be entirely or partially dissolved by the wash water if the ordinary methods were followed. This solution of the core may be partially or entirely prevented by using a saturated solution of the material through which the drill is passing, in place of pure water.

94. Methods Adapted to Soft Materials.—Some ores are so soft that it would be impossible to obtain a complete core while using wash water, as the soft portions would be ground up and washed away, leaving only the harder material in the core barrel. The soft portions are often the most valuable part of the ore, and hence it becomes necessary to obtain samples for analysis. This may be accomplished by running the drill dry, continuing the work until the bit blocks or shows signs of blocking, when the rods with the plug or core of ore that has forced its way into the core barrel are withdrawn from the hole. It is sometimes necessary to plug the upper end of the core barrel with a piece of wood to keep the water that accumulates in the rods from forcing the plug or core of ore out through the core barrel and bit while the rods are being drawn from the hole.

When the drill runner encounters a body of soft ore, such as hematite iron ore, this method of drilling may be continued while passing through the ore body, or part of the distance may be drilled in the ordinary manner, depending on any fragments of core that may remain in the core barrel, the wash, and the behavior of the drill to indicate the character of the deposit passed through. It is only the soft iron ores that give this trouble, for the hard hematites and magnetites furnish good cores. By this method of dry drilling, sample cores may be obtained from any soft material that partakes of the nature of clay.

SPECIAL ADVANTAGES POSSESSED BY THE DIAMOND DRILL

95. A given formation can be penetrated much quicker with a diamond drill than with a shaft. The cost per foot is much less in the case of drilling than in the case of shaft sinking; hence, with a given amount of money, more strata can be penetrated with a diamond drill than by a shaft.

When a prospecting shaft is abandoned for a short time, it fills with water, which has to be removed before the sinking can be continued, while if a diamond-drill hole is left idle and the stand pipe or casing undisturbed, there is no expense for removing the water from the hole before drilling can be resumed. If work in a shaft is stopped for a holiday or over Sunday, there is always a stand-by loss for pumping, which is avoided in the case of a diamond-drill hole on account of the fact that the water in the hole does not interfere with the drilling.

THE DEPENDENCE THAT CAN BE PLACED ON THE APPARENT LOCATION OF ANY POINT IN A DIAMOND-DRILL HOLE

96. Dipping Strata.—When the diamond-drill hole cuts the formation at an angle, the core may show the angle the strata makes with the center line of the hole, but it gives no record as to the direction of the dip of the strata. Fig. 74 shows a diamond-drill hole passing through an inclined stratum, and Fig. 75 shows the core taken from the same formation. During the operation of drawing the rods from the hole, it is more than likely that the core will be turned from its original position, thus giving no idea as to the direction of the dip of the stratum.

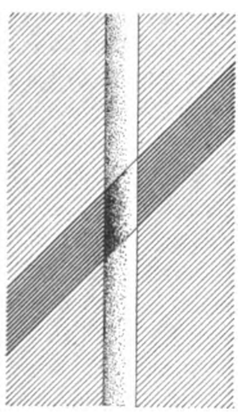


FIG. 74

FIG. 75

97. It was originally supposed that all diamond-drill holes went straight and true; and that no matter in what direction the hole was started, it would continue in that direction throughout its entire course, but as deposits discovered by the diamond drill were mined, the lower ends of the holes were frequently found a long distance from their supposed positions. This variance led to a great many theories as to the cause of the *drift*, or change of direction; some thought that the drill hole had a tendency to go across the rock formation, while others claimed that it had a tendency to follow the strata. In fairly hard and uniform material it was observed that inclined holes had a tendency to rise as they advanced, while vertical holes would sometimes take a spiral course or travel off to one side.

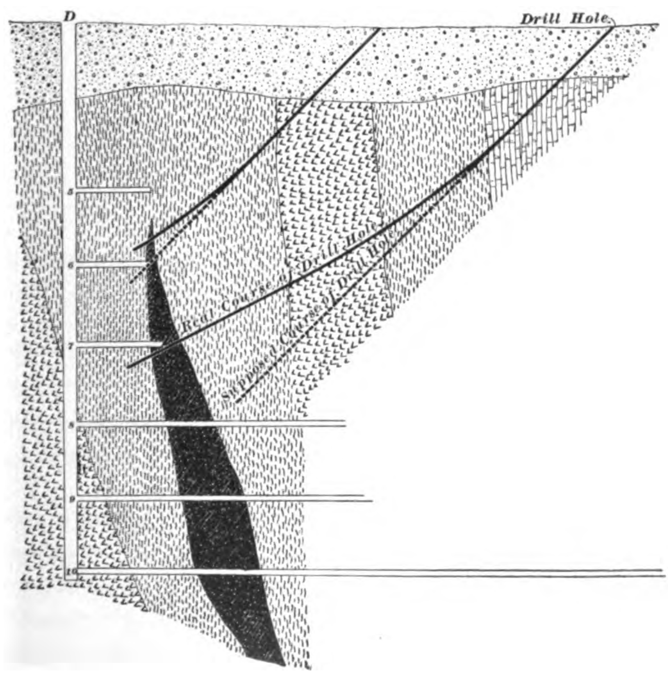


FIG. 76

Fig. 76 represents a diamond-drill hole put down south of the "D" shaft of the Chapin mine in Michigan. After the shaft had been sunk and the drifts run out, the end of the hole was discovered 96 feet above and 70 feet south of its supposed location. The dotted line shows the supposed course of the drill hole, while the full line shows its real course.

Fig. 77 illustrates the course of a vertical hole drilled by the Hamilton Ore Company, and afterwards followed down in the construction of their No. 1 shaft. *A* is the location

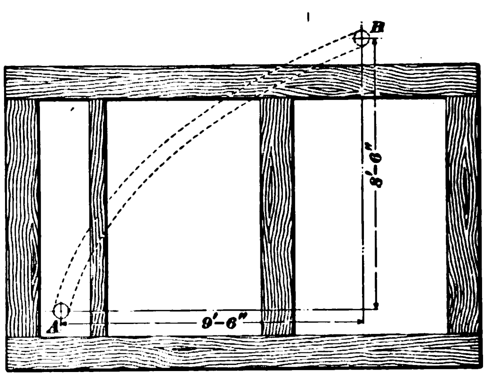


FIG. 77

of the hole on the surface, and *B* is the place where it disappeared 490 feet below the surface. The dotted lines show the course of the hole for the 490 feet that it was followed.

98. Bore-Hole Drifting.—The principles underlying this tendency to drift from the purposed course are simple, and may be explained as follows:

Suppose, for example, that it was desired to drill a downwardly inclined hole through a hard and uniform rock, such as quartzite. The diamond bit is always of greater diameter than the rods that follow it. If this were not the case, and the bit were not kept absolutely to gauge, sooner or later the rods would stick in the hole. If the rods were the exact size of the hole, it would be necessary to cut grooves on the outside of them for their entire length, in order that the water which is forced down through the inside to cool the carbons and wash away the cuttings might be allowed to ascend on the outside. The core barrel is sometimes made to fit the hole quite closely, being provided with spiral grooves on the outside, through which the water can ascend.

For simplicity, suppose that the hole had been drilled for a few feet perfectly straight, and with its end perpendicular to the center line of the hole. Now, suppose that a full-sized bit with a very small core barrel and rods were introduced to continue the work. They would assume some such position as that shown in Fig. 78; that is, the bit, being of the same diameter as the end of the hole, would of necessity occupy a position practically concentric with that of the hole, while the rods, owing to their flexibility, would sink down into contact with the lower side of the hole. This

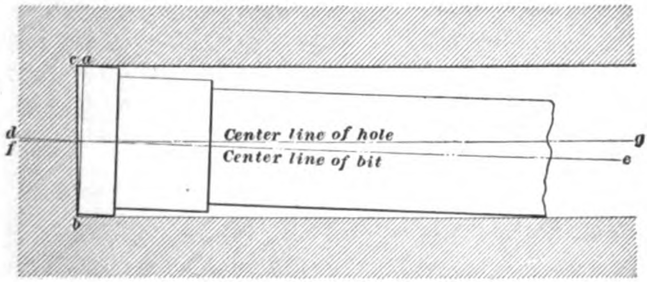


FIG. 78

action would result in throwing the face of the bit into such a position that the plane of the end of the hole and the plane passing through the end of the bit would form an angle *a b c*. As the direction of the hole at any instant is perpendicular to the plane in which the diamonds rotate, it is evident that, with the rods in the position shown, the hole would have a tendency to progress along the line *d c* instead of along the line *f g*. In other words, the course of the hole would begin to rise, and as the drilling progressed, this tendency would continue and the course of the hole would be constantly ascending.

Fig. 79 is a sectional plan (*a*) and elevation (*b*) of a diamond-drill hole illustrating this tendency to rise. The heavy lines *A B* show the actual course and the dotted ones *A B'* the proposed course.

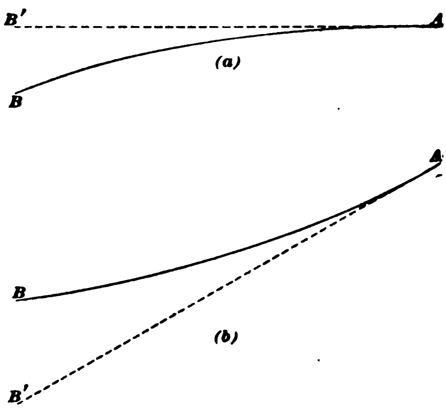


Fig. 79

99. Vertical Rise. The **vertical rise** is not the only tendency to drift caused by the rods being of smaller diameter than the bit. By referring to Fig. 80, it will be seen that if the drill rods rotate in the direction of the hands of a watch, they will tend to roll to the right, into the position shown by the full lines. This would carry the point *A*, Fig. 81, over into the position shown. Now, it was seen that when the center of the rods at the point *A* dropped below the center of the hole, the course followed by the bit was an upward curve. In like manner this rolling action tends to carry the rods to the right, and the point of the hole would deflect to the left, as shown in Fig. 79 (*a*). In drilling through hard rock, great pressure has to be put upon the bit to make the diamonds cut, and this pressure increases the tendency to drift by springing the rods against the side of the hole. It has been claimed that at times the

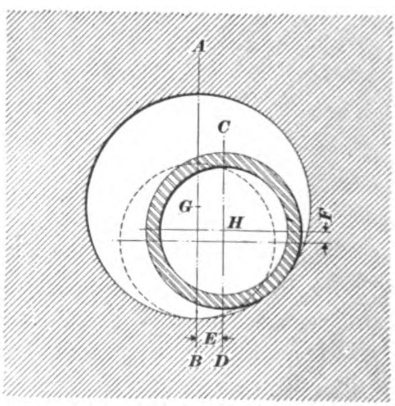


Fig. 80

outside of the core barrel may be forced into contact with the inside of the hole within 2 or 3 feet of the face of the bit, that is, when using small-sized bits not over 2 inches in diameter. Old or worn core barrels are sometimes as much as $\frac{5}{16}$ inch smaller in diameter than the bit; such a great difference in diameter causes the hole to curve very rapidly.

Fig. 80 shows that as the rods roll to the right, through the distance *E*, their center is carried upwards through the distance *F*. This vertical rise will tend to neutralize the

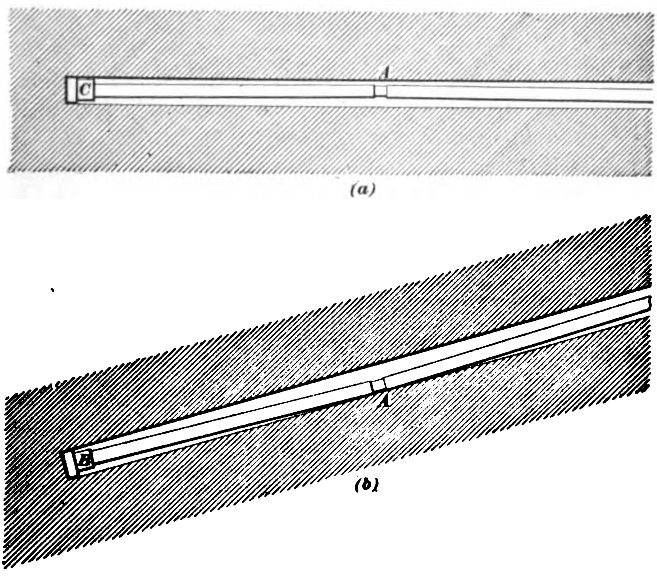


FIG. 81

angle caused by the point *A*, Fig. 81, coming into contact with the bottom of the hole. Hence, the horizontal drift partially neutralizes the rise.

Unfortunately, all material drilled through is not hard and uniform in structure, therefore other factors enter into the problem to complicate matters and carry the end of the diamond-drill hole from its purposed course. In drilling through soft material, the drill rods enlarge the hole by rubbing, and this increases the tendency to drifting.

In some cases this drifting may not be an altogether unmitigated evil, for if it were desired to make the end of the hole rise in order to reach a certain point in the formation, this may be accomplished by using a core barrel very much smaller than the bit and by pushing the work as rapidly as possible. On the other hand, if it is desired to keep the holes straight, a core barrel of practically the size of the bit should be used. It has been proposed that bushings set with diamonds be placed back of the bit or core barrel to keep the center of the bit in line with the center of the hole.

100. At times, pockets, vugs, or cavities are encountered in the formation, and these may be lined with hard crystals. The bit coming against the face of one of these openings at an angle may be forced from its course. The hole may be at an angle to the strata passed through; this will undoubtedly have an effect upon the drift, especially when the formation is composed of alternate layers of hard and soft material.

When drilling through soft material, the bit cuts very much faster and requires less pressure upon the rods. This reduces the tendency of the rods to spring against the side of the hole, and is one of the reasons why the bit has less tendency to rise in drilling an inclined hole through soft material than when drilling through hard material.

101. Surveying Diamond-Drill Holes. — Formerly it was the custom for the engineer in charge of the mine to take the angle of the hole at its collar and plot this angle on the mine map, indicating the various strata passed through as occurring along this line and at their respective distances from the collar, as shown by the core. From what has already been said in regard to drifting, it is evident that these results were frequently very much at fault.

In 1880, Mr. G. Nolten, in Germany, proposed to fasten a small bottle partially filled with hydrofluoric acid into the core barrel just above the bit, and to lower this to the bottom of the hole, leaving it in that position a sufficient length of time for the acid to eat a ring on the inside of the glass. Upon drawing the rods and the bottle from the hole, the surface of the liquid in the bottle could be made to coincide with the ring on the inside of the glass and this angle measured. By making such observations at frequent intervals during boring, and plotting the results, a vertical projection of the hole can be obtained, as illustrated by (*b*), Fig. 79. But this gives no information as to the horizontal drift of the bit. A bottle that has been used and acted upon by the acid is shown in Fig. 82.

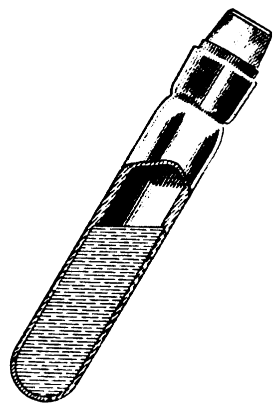


FIG. 82

In case there is much water in the drill hole, it may be necessary to plug the upper end of the core barrel with a piece of wood, in order to prevent the water in the rods above from forcing the bottle of hydrofluoric acid out of the bit while the rods are being drawn from the hole.

102. Gelatine Indicator.—In 1883, Mr. E. F. MacGeorge, an Australian engineer, invented and used the following process: He filled small glass tubes with gelatine, in which were suspended glass plummets and magnetic needles. By heating the gelatine to 180° Fahrenheit, which rendered it liquid, inserting the tubes into the hole at various points and leaving them until the gelatine solidified, he could, upon removing the tubes, compare the angles between the compass, the plummets, and the center of the rod. This information enabled the course of the hole to be plotted with fair accuracy. The method can be used where there is no magnetic attraction, but in the vicinity of magnetic iron-ore deposits it would be of little or no use.

103. Drifting Profiles.—Fig. 83 represents a profile showing the curvature of nine holes drilled and surveyed under the supervision of Mr. J. Parke Channing. In the case of hole number *1*, the core barrel was fairly new; in number *2* a new core barrel was introduced near the latter

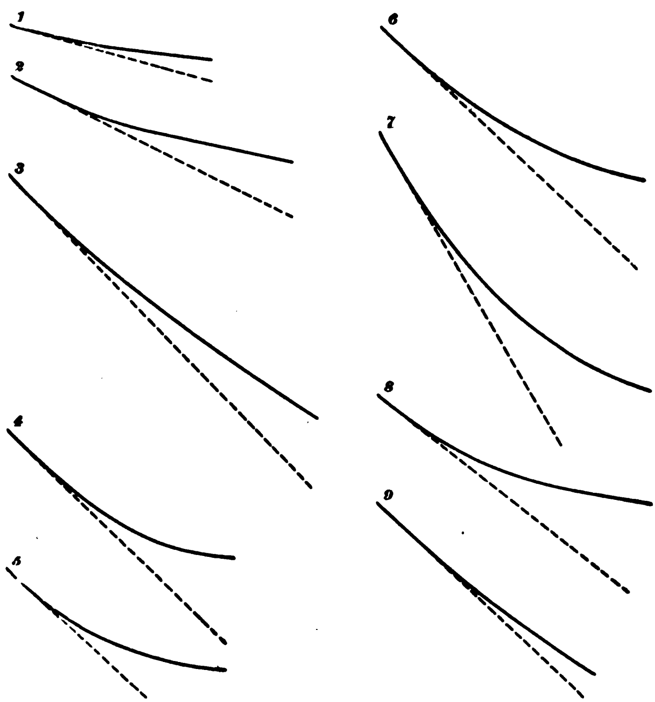


FIG. 83

part of the work, and thus kept the end of the hole straight; number *3* was drilled before the core barrel had worn much, and consequently it has a fairly true course; numbers *4*, *5*, and *6* are more or less curved; in the case of number *7* it was desired to strike the formation at a certain point, and in order to accomplish this it was necessary to keep the hole from flattening if possible. This was attempted by using special couplings (made of steel and hardened), which were introduced between the rods and the core barrel. They wore away quite rapidly, and the attempt does not seem to have been very successful. In the case of number *8*, it was desired to make the hole rise as much as possible, and this was accomplished by using an old, worn core barrel and a large bit. Number *9* was kept practically straight by using a new core barrel and a bit with but little clearance.

HAND BORING TOOLS

104. Hand Augers.—In places remote from drill rigs, or where it is difficult for some cause to obtain and place them, or where exploration is not considered sufficiently important to warrant the expense of hiring or purchasing a rig and importing expert labor to run it, hand augers may prove serviceable. The hardness of the rock material in which such tools are employed will determine the kind of auger to be used. Experience has taught that the auger shown in Fig. 84 is suited to earth and clay. Fig. 85 is an auger suitable for caving materials, but it may be necessary to drive casing in such materials. The auger shown in Fig. 86 is suited for sandstone and soapstone formations and even crystalline limestone. The drill stem is of standard pipe, made into short lengths and threaded. The clamp lever *a* in the drill rig, Fig. 87, is used for turning the rods. A small rope swivel *b*

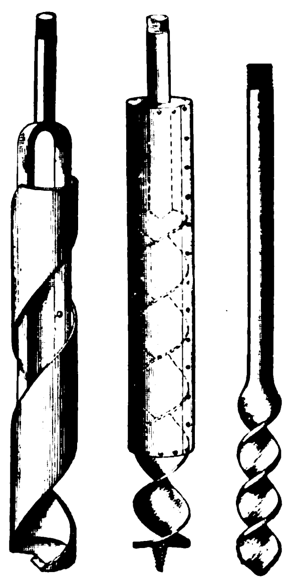


FIG. 84 FIG. 85 FIG. 86

for hoisting the rod is also needed. The derrick *c* and crab winch *d* are also necessary for heavy work. These rigs can be worked by horsepower with probably greater satisfaction than by hand.

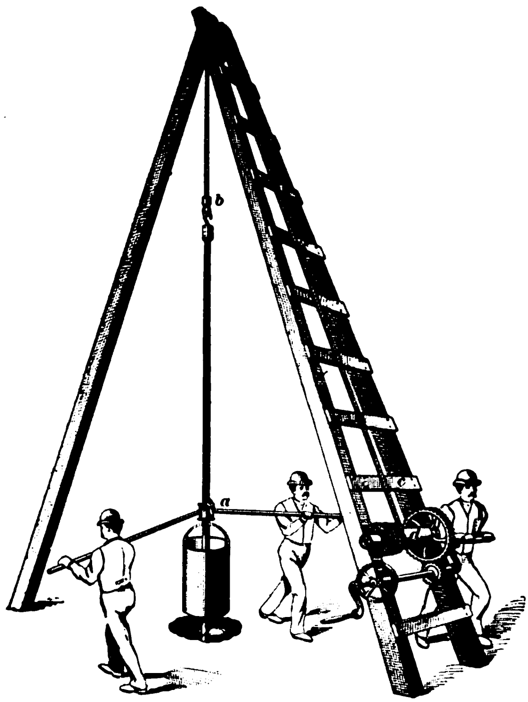


FIG. 87

It is sometimes necessary to bore in comparatively soft material near the surface, as for instance, when searching for iron ore in clay beds or for deposits of manganese ore, bog-iron ores, phosphate rock, clay, etc. For this work a simple auger may be used, as shown in Fig. 88. This is usually composed of a bar of steel, or of iron with a steel tip, which is twisted to a spiral form and the point of which is split and sharpened. A good length for the auger is about 13 inches, with a diameter of 2 inches; it should have about 4 turns. A piece of 1-inch pipe threaded at one end is welded to the auger as a stem; and as the boring progresses, other pieces are screwed to it by means of ordinary pipe couplings. The auger is turned by a handle arranged with a central eye, so that it will slide up or down the pipe and fasten at any desired point by a setscrew. In case hard rock is encountered when prospecting with this outfit, it is possible to continue the work by means of a churn drill formed by a piece of $1\frac{3}{8}$-inch octagon steel having a 2-inch cutting edge, and with a piece of pipe welded to its upper end. For the first section of rod above the steel chopping bit, a piece of $1\frac{1}{4}$-inch round iron may be substituted for a section of the pipe. This has the advantage of giving the necessary weight to the churn drill for driving it through the formation. Prospecting has been carried on to a depth of over 60 feet with such appliances, the churn drill being substituted for the auger bit when hard rock was encountered. This outfit costs but little, and can be made or repaired at any blacksmith shop. When using the chopping bit, the material drilled may be worked stiff so that the debris can be removed by means of the auger bit, or it may be liquid, and a sand pump made from a piece of pipe with a leather valve at its lower end may be employed for sludging the hole. During the work sufficient water is introduced into the hole to keep the tools cool and assist cutting.

FIG. 88

SPRING-POLE BORING

105. The **spring-pole** system of boring is used in drilling comparatively shallow holes for water supply or prospecting. The apparatus, Fig. 89, is a slender pole *P* having considerable spring. Its large end is embedded in the ground by digging a ditch in the direction in which the pole must be when in place, and another ditch at right angles to the first one, in which the log *l* is placed over the large end of the spring pole. At a point about midway between the ends of the spring pole, a support *S* is placed, giving the pole an inclination of about 30°. The large end of the pole and also of the log *l* are then weighted down with stone, to prevent any movement while the operation of drilling is going on. The bore rods are attached to the

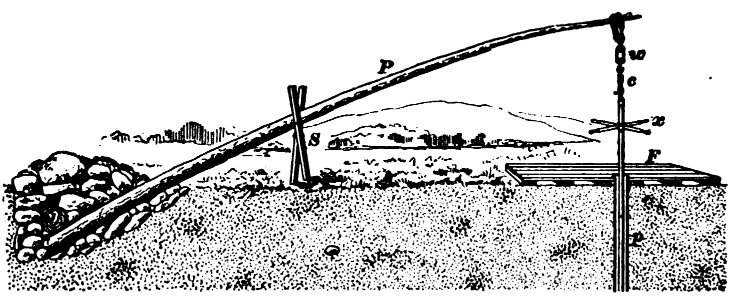


FIG. 89

small end of the pole by a chain *c* and swivel *w* in such a manner that the drill rods are held in equilibrium by the spring of the pole. The rods are operated by two or four men, who take hold of the handles on the cross *x* and alternately lift and force down the drill rods, and at the same time turn them, either by walking around the top of the hole on the platform *F* or by passing the handles of the cross *x* from one to the other after each blow.

A number of short drill rods are used near the top of the hole, so that the entire length of the rods can be lengthened whenever the cross *x* becomes too low for the men to effectively operate it. These short rods are finally replaced by a long one and again used as before.

Before starting the hole, it is necessary that a pipe *p* be driven into the ground to guide the rods, and in the event that the surface is rocky, a guide hole is bored with the hammer and drill or jumper. In either case, the pipe should be vertical, so that the hole proper will continue vertically downwards. Water is poured into the hole when necessary, and the debris removed by means of a sand pump.

The energy of the drillers is exerted in forcing the rods downwards, and being aided by the weight of the rods, the bit strikes the rock with considerable force. By means of the spring pole, holes can be drilled to a depth of 150 feet.

Sometimes when it is not essential to have a hole bored in any exact location it may be started under a tree having a suitable branch that can be used to perform the same function as the spring pole. Or the drill rods may be suspended from the middle of the branch and ropes tied to its end, which are pulled by men until the bit has reached the bottom of the hole and considerable slack is produced in the chain supporting the rods. Then, by suddenly releasing the ropes, the bit is made to strike the bottom of the hole a number of times by the vibration of the branch. The men then repeat the operation, and in this manner continue the hole to the required depth.

ROCK DRILLING

INTRODUCTION

1. Definition.—Drilling as here used is the operation of making holes in rocks prior to blasting. A **drill** is (1) a bar of round or octagonal steel cut to any desired length, and having one or both ends forged into a cutting edge and hardened so that it will penetrate rock when struck against it; and (2) a piece of flat steel twisted into the shape of an auger and with one end forged and hardened so that it will when rotated penetrate the rock against which it is pressed. The drill chips or crushes the rock into small fragments, which usually readily fall from the hole if it is drilled upwards, but when holes are driven downwards or do not clear readily, the fragments of rock are removed either by a scraper, a swab, or by a stream of water forced to the bottom of the hole.

The subject of drilling naturally divides into *hand drilling* and *power drilling*, according as the means for operating the drill is furnished by hand, or by steam, compressed air, or electricity. In both of these methods the drills used are either percussive or rotary. *Percussive drills* are those that chip the rock into fragments by blows; *rotary drills* are those that cut the rock by their rotation.

HAND DRILLING

PERCUSSIVE HAND DRILLS

2. Percussive hand drills are divided into (1) *churn drills*, in which the blow is given by the force of the drill hurled, or at times simply dropped into the hole; (2) *hammer drills*, or *jumpers*, in which the drill is held by hand while the blow is struck on the head of the drill with a hammer. When a man holds the drill in one hand and strikes it with a small hammer held in the other hand, the operation is termed *single-hammer work*. When one man holds the drill and another strikes it with a long-handled hammer the operation is called *double-hammer work*.

Percussive hand drills have a shank *b*, Fig. 1, and a bit, or cutting edge, *a*, which is made wider than the diameter of the shank *b* to prevent the drill sticking in the hole, and to allow the cuttings made to move away from the bottom of the hole. The amount of clearance thus given depends on the hardness of the rock, length of the drill, and the size of the steel, and varies from $\frac{3}{8}$ inch to $\frac{7}{8}$ inch, but is best determined by experiments in any particular rock. When the clearance is too large, the points, or corners, of the bit are easily broken, especially with brittle steel and hard rock.

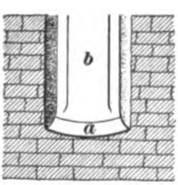


FIG 1

Table I shows the average clearance given to hand drills for work in rock of moderate hardness.

It will be observed from the table that the average clearance given a drill is about one-half the diameter of the shank.

Very hard rocks require drills of somewhat less clearance than is given in the table. A very common clearance used for rock drills is $\frac{3}{8}$ inch, while for coal drills it is greater.

TABLE I

AVERAGE CLEARANCE GIVEN HAND DRILLS

Width of the Bit Inches	Diameter of the Shank Inches	Clearance Inches
1	5/8	3/8
1 1/8	3/4	3/8
1 1/4	7/8	3/8
1 1/2	1	4/8
1 3/4	1 1/8	5/8
2	1 3/8	5/8
2 1/4	1 1/2	6/8
2 1/2	1 5/8	7/8

3. Cutting Edge.—The form of the **cutting edge** of the bit depends on the hardness and character of the rock, the diameter of the hole, and the force of the blow. To find the proper form of cutting edge for a particular stone, a number of tests should be made with different bits to

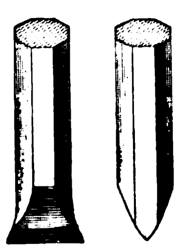


FIG. 2

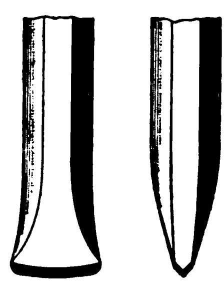


FIG. 3

determine which kind is best suited for the case in hand. The bit shown in Fig. 2 has a thin, sharp, straight, cutting edge, which is used in light single-hand work for block holing, and in the hands of an expert driller cuts rapidly and lasts well. The cutting edge is sometimes even given a slightly concave instead of a straight edge for a moderately hard even-grained stone. Since the edge of a straight bit is weak and the corners are liable to chip off in the hands of an inexperienced man, it is customary to curve the cutting edge as shown in Fig. 3. This convex form tends to equalize the wear on the bit by throwing the greater force of the blow on the center, where the bit is strongest, and thus furnishing a tool that will not dull so quickly, nor chip off at the corners when the greatest resistance is encountered.

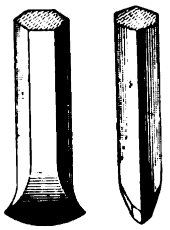


FIG. 4

Fig. 4 is a form of bit similar to that shown in Fig. 3, but having a blunter edge it is better adapted for drilling in very hard rock.

A soft sandstone composed of hard grains of quartz cemented together with soft material is more easily disintegrated by pounding with a blunt-edged bit than by cutting. Fig. 5 shows a flat-edged bit frequently used for drilling in a soft sandstone that crumbles readily. The side *a b* and the end *c d* of the cutting edge are both

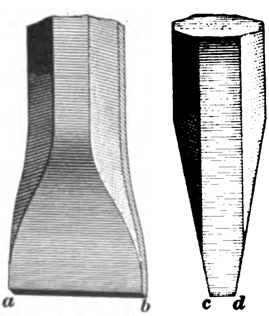


FIG. 5

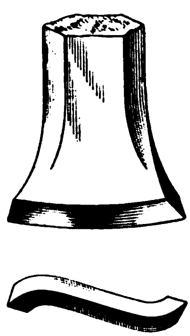


FIG. 6

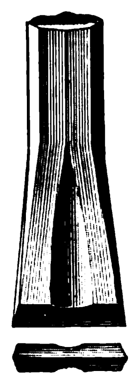


FIG. 7

straight. A flat-edged bit is not, however, used in calcareous sandstones, where the quartz grains are cemented by a hard material.

In seamy or broken ground the ordinary bit is apt to become wedged in crevices and stick in the hole. This difficulty may be overcome in a large measure by turning the corners of the bit as shown in Fig. 6, thus giving the form of the letter *S*, which prevents the drill from sinking too far into the soft rock, or from entering a seam or crevice. Before the corners are bent, the bit should be given a slightly greater clearance.

The bit shown in Fig. 7 is provided with side grooves to allow the material to work upwards and permit freer cutting at the bottom of the hole. This principle is applied to flat-edged bits in the Berea Grit of Ohio, which is a friable sandstone.

4. Drill Sets.—Drills are made with various lengths, dependent on the depth of hole to be drilled. For drilling holes of any considerable depth, drills are made in sets of three or more, Fig. 8, having lengths that are increased as

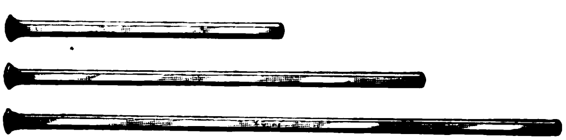


FIG. 8

the hole is deepened; each longer drill of the set commonly has a slightly smaller diameter, about $\frac{1}{8}$ inch, than the next shorter. The shorter the stock, the more effective is the blow; therefore in hand drilling the hole is usually started with a drill about 18 inches long. Short drills are not as flexible or elastic as long drills and do not spring or jump as much as longer drills. The next longer drill of the set is used to drill to as great a depth as its length will permit; then the next longer drill of the set follows; and so on until the hole has reached its full depth.

While it is desirable to have the drill hole uniform in diameter throughout its entire depth it is not possible, as the bit corners wear off, and where drill sets are used that portion of the hole made with each succeeding bit is of course smaller than the preceding portion. For these two reasons, a drill hole is slightly funnel-shaped; that is, it decreases in diameter toward the bottom, a condition that operates against obtaining the best results from an explosive.

THE CHURN DRILL

5. The **churn drill** has a shank from 6 to 10 feet long and occasionally with a bit at each end. The force of the blow given with such a drill depends largely on its weight, which is sometimes increased by an enlargement, as shown in Fig. 9. A drill of this description is usually made with a short and long end; the hole is started with the short end of the

FIG. 9

drill, and when it has reached such a depth that the enlargement prevents further drilling with that end, the drill is reversed and the other end is used to deepen the hole.

To use the churn drill, it is drawn a short distance from the inner end of the hole, given a slight turn, and then hurled or dropped back. Unless the proper turn is given the drill, the bit slides into the previous cut and becomes wedged, producing what is called *fitchering*. Fitchering is perhaps more common with churn drills than with other forms of hand drills.

The churn drill is used for drilling vertical, inclined, or horizontal holes, but is most effective in drilling vertical holes downwards, because then the entire weight of the drill being accelerated by gravity, the force of the blow is increased. It is not as effective in drilling holes upwards, since the acceleration of gravity decreases the force of the blow. The drill is used single-handed or double-handed in rock; that is to say, either one or two men operate it, according to its weight; but in drilling a vertical hole with a long heavy churn drill, two men can work to better advantage than one man, as one man spends much of his energy in lifting the drill and cannot therefore impart much force to the drill on its downward stroke. On the other hand, two men use less energy between them in lifting the drill and consequently can exert more than double the force of one man on the downward stroke. They can also lift the drill higher in boring downwards, thus increasing the force of the blow on account of the increased length of stroke. The weight of the drill should be such that the drill will not rebound or have its cutting force materially affected by the powdered rock at the bottom of the hole.

Churn drills are largely used in anthracite mining, and a common form is shown in Fig. 10, which is a combined drill and tamping bar. These anthracite drills are usually made

FIG. 10

of $\frac{7}{8}$-inch round iron about 6 feet long to which is welded a steel cutting point. The tamping end should be of copper, to limit the danger of striking fire when tamping holes.

THE HAMMER DRILL

6. The **hammer drill,** or **jumper,** is generally shorter than the churn drill, has a bit on only one end, and is driven by a blow delivered on the head of the drill with a hammer. These tools are used for drilling in most all kinds of rock, the weight and character of the drill and of the hammer varying with the character of the work in hand.

7. Single-hand work is performed by one man who holds the drill firmly in one hand, and strikes it with a small hammer held in the other hand, Fig. 11.

FIG. 11

The single-hand hammer has a wooden handle 10 inches long, Fig. 12, and weighs from 3 to 5 pounds. Drill steel for single hammers varies from ½ to 1 inch in diameter, and the bit is usually forged like those shown in Figs. 2 and 3. In many cases no distinction is made between the form of bit used in single-hand and double-hand work, although a bit for single-hand work can be sharper and more pointed than one intended for double-hand work. Single hammers are used when drilling shallow holes, not generally exceeding 2½ feet in depth. Such holes are made in large boulders so that they can be broken and more easily handled. Single hammers are also extensively used in metal mining where

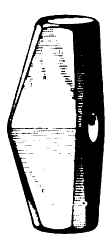


FIG. 12

veins are small, or where it is desired to keep the ore and gangue separate.

8. Double-Hammer, or Double-Hand, Work.—This work is performed by two men; one man holding the drill with both hands, while the blow is struck by the other man with a double-faced, two-handed, striking hammer. Fig. 13 shows the head of such a hammer, that weighs from 6 to 8 pounds. In mine work, the two-hand hammer head averages about 6 pounds in weight and has a stiff handle about 20 inches long. In outside rock work, the handle may be about 30 inches long and limber and the weight of the hammer head 7 to 8 pounds.

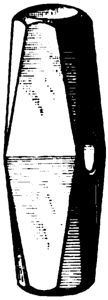


FIG. 13

9. Three-Hand Work.— Here three men are employed, a drill holder, or helper, and two strikers using

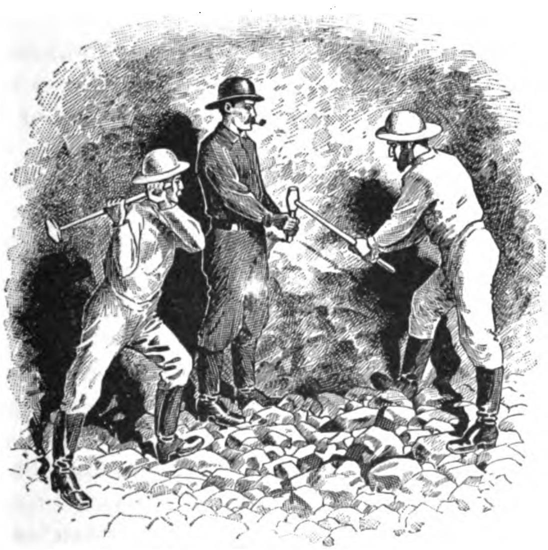


FIG. 14

striking hammers, Fig. 14. The helper holds the drill steady with both hands, while the blows are delivered alternately by the two strikers. Much time is saved by this method of drilling, as the blows are delivered twice as rapidly as in double-hand work. Greater caution, however, is required to prevent injury to the drill holder, and expert strikers only are employed. As the drill is struck a much harder blow in double-hand or three-hand work than in single-hand work, the bit must have an edge suited to this harder blow, and the forms shown in Figs. 3 to 7 are those commonly used.

10. Using the Hammer.— The proper use of the hammer requires thought upon the part of the driller. An experienced contractor knowing this usually when hiring a man requires him to give an exhibition of his method of swinging and striking with his hammer. A good hammersman takes advantage of the recoil of the hammer, while the inexperienced man does not, and, consequently, tires sooner. In swinging a stiff-handled hammer, the arms and body do most of the work, while with a limber-handled hammer the arms and shoulders with but slight movement of the body do the work. The breathing should be timed with the blows. The muscles should be relaxed immediately previous to the blow, as the striker is then not seriously affected by the vibration, or force, of the blow, and the hammer is very readily caught on its rebound for the upward swing. Long experience only can render a striker expert in swinging a hammer, or enable him to deliver an efficient blow that will not tire the body.

11. Relation of Weight of Hammer to Drill.—The driller should approximately proportion the weight of his hammer to that of his drill. When a light hammer is used to strike a heavy drill the force of the blow seems to be lost in the drill and little work is performed by the cutting edge. The reason for this is found in the fact that as steel is elastic, its particles are capable of a limited motion among themselves. Hence if the weight, or mass, of the drill is very large, as compared with that of the hammer, the force of the blow delivered by the hammer may be wholly consumed in vibrating the drill and heating up the head. Under such conditions the blow will not move the drill forwards or cause it to perform any work in cutting the rock. For example, if a 3-pound hammer strikes equal blows on a 3-pound, 6-pound, and 12-pound drill, the relative force of the respective blows is given by the ratio of the weight of the hammer to that of the drill, and is $\frac{3}{3} = 1$; $\frac{3}{6} = \frac{1}{2}$; $\frac{3}{12} = \frac{1}{4}$. If too light a hammer is used in a hard rock, it will rebound and a ringing sound will be produced at every blow similar to that produced by striking the face of an anvil with a hammer, showing that more or less energy is being wasted in vibration.

It is not practicable or necessary to determine the exact efficiency of the hammer and drill, but an experienced driller soon determines by the sound and feel of the drill when he strikes it whether or not the hammer and drill are suited to each other and to the work in hand. The weight of the drill and the character of the bit chosen for any work should correspond to the character of the rock to be drilled, and the weight of the hammer should then be adapted to the weight of the drill.

12. Relation of Velocity to Force of Blow.—The force of a blow delivered by a drill or hammer depends on the weight, or mass, of the drill or hammer striking the blow, and the velocity at the moment of impact. Calling the mass m, and the velocity v, the force of the blow is $m v$. Hence, the blow that a given hammer will deliver varies with the velocity at the moment of impact. The energy stored in the hammer, or the work performed by the blow, varies as the weight, or mass, of the hammer and the square of the velocity at the moment of impact. For example, a blow struck when the velocity of the hammer is 20 feet per second, will have twice the force, and theoretically perform four times the work that it will when the velocity is 10 feet per second; or an 8-pound hammer will strike a blow twice as hard, and perform twice the work of a 4-pound hammer at the same velocity in the same rock. There is a limitation to this, for if twice the velocity is given to the drill, the rock will offer four times the resistance and surplus energy will be expended in mashing down the head of the drill, rather than in doing useful work. This would be particularly the case if the hammer and drill were not proportioned to increased velocity, for action and reaction are equal. The velocity of the blow at the moment of impact depends on the length of stroke or the distance through which the hammer or drill is moved.

13. Cleaning Drill Holes.—In drilling a *dry hole*, that is, one in which water is not used, unless the hole is driven

FIG. 15

upwards at an angle greater than 12° with the horizontal, it is necessary to use a *scraper* to clean out the small pieces of rock that accumulate. The scraper used for the purpose, Fig. 15, is of round iron, usually about $\frac{3}{8}$ inch in diameter, with one or both ends flattened and turned up at right angles. It is made of any convenient length to suit the depth of the hole to be drilled.

It is much better, however, to use water in the holes whenever possible, as the commotion of the water caused by the drilling drives the small pieces from the bottom and floats more or less of the fine material, thus keeping the bottom of the hole clean for the drill.

Holes in which water is thus used, called *wet holes*, are cleaned by *swabs* made of round green sticks that have been broomed at one end by pounding with a hammer. When a wet hole needs cleaning, water is poured into it and the swab is run in and out several times. Each time the swab is run to the bottom of the hole it is turned so as to take up the sand, and after it has been carefully withdrawn it is struck on some object to remove the sand and mud from it. In the hole that is only moderately wet the powdered rock forms a paste, or mud, that can easily be removed with the scraper. When water is used in the hole it is customary to wrap a wisp of hay or grass, or to tie an old rag, around the drill to keep the water from splashing out of the hole.

14. Cost of Drilling by Hand.—At many mines the drillers work on contract; the stint, or amount of work done in 8 hours, being 9 lineal feet of hole for two men, while three men are supposed to put in 12 feet. In contract driving this work is largely exceeded by the contractors, but it may be taken as an average basis for a day's work in hard rock. If the price of labor is $2.50 a day for example, the cost of drilling 9 feet would be 55 cents per foot. Where three men are at work, two hammermen and a drill holder, the latter receives about $1.50 a day and the former receive $2.50 each, thus making the cost of drilling 12 feet about the same as when two men drill 9 feet. Of course, the hardness of the rock has much to do with the rate at which holes may be drilled. At a drilling contest in the West, two men drilled 36 inches into hard granite rock in 15 minutes, striking 72 blows per minute. The nearest competitors drilled 31⅞ inches in the same time. Of course, such a rate of drilling could not be continued long, but it shows what men can do in the way of rock drilling when they exert themselves.

HAND ROTARY DRILLS

15. Rotary drilling is any form of drilling in which the drill is turned and pressed forwards at the same time. The action of the rotary drill is to cut or wear away the rock at the bottom of the hole in a plane nearly perpendicular to the axis of the hole, instead of chipping and crushing the rock into small fragments in planes parallel to the axis of the hole, as is done by percussive drills. Rotary drilling may be divided into two systems: *direct drilling*, represented by the breast auger, in which the drill is rotated by a crank formed by a bend in the shank of the drill, and the drill advanced or kept up to its work in the hole by the pressure of the body against the end of the drill, and *machine drilling*, in which the drill is rotated directly by a crank at the end of the drill, by a side crank and bevel gears, or by a ratchet-and-pawl arrangement; but in all these cases the drill is advanced in the hole by a feed-screw.

BREAST AUGERS

16. Several forms of **breast augers** in common use are shown in Fig. 16. The auger may consist of a solid shank having a twist drill at the boring end, and a bend to form a crank at the other end; the handle of the crank is supplied with a muff to protect the hand. The yoke *a* or breast-plate *b* for pressing the drill into the hole is usually a separate piece, as shown in the figure. The crank is often made separate so that it may be applied to drills having different

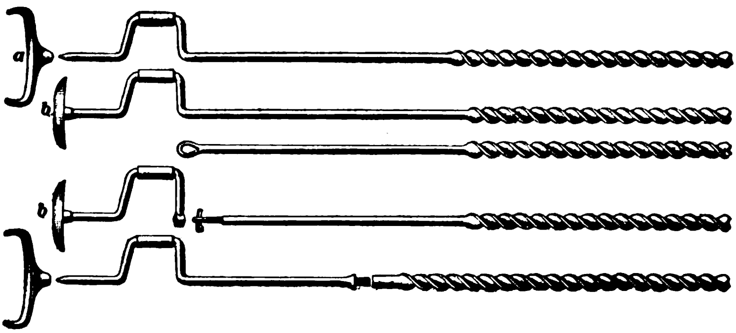


FIG. 16

lengths, and if constructed in this manner it does not need to be sent to the shop when the bit is sent to be dressed. At times the crank is attached to the drill shank by a screw joint; at other times the shank has a plain square end to which the crank is fastened by a cotter. All these forms, and one with an eye in which a straight handle is fitted, are shown in the figure. The length of this drill when made in one piece is commonly 6 feet. It bores holes from 1½ to 2½ and even 3 inches in diameter when desired, 2 inches, however, being the most common size used.

17. Auger Bit.—The auger has a **V**-shape or split bit of the form shown in Fig. 17. The **V** cut out of the center should be a little more than one-third of the width of the bit or cutting edge; it should be a broad shallow cut in order that the corners or remaining edges of the bit shall be as strong as possible. This form of bit penetrates coal or soft rock rapidly and with less labor than any other form, and it is easy to repair and sharpen. In drilling soft coal, the **V** cut can be enlarged and the drilling thereby made more rapid. The miner keeps the cutting edges sharp by the use of a file until the bit has become worn and does not provide sufficient clearance for the drill in the hole, then it is dressed by the blacksmith. The twist drills are usually made from the best crucible steel in sets having 2-, 4-, and 6-foot lengths. The twisted shank of the drill serves to clear the hole of the cuttings sufficiently to allow the bit to advance. At times, however, the drill clutches and must be removed and the hole cleared with a scraper, as in the case of the percussive drill. To use this drill, the miner presses with his shoulder against the yoke *a*, or with his breast against the plate *b*, while he rotates the drill by the crank. Drilling with breast augers is hard work, but the boring proceeds rapidly in coal of moderate hardness.

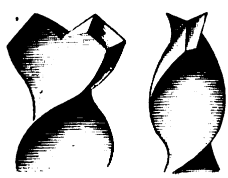


FIG. 17

HAND MACHINE DRILLS

18. Types.—The several forms of **hand machine drills** differ from the breast auger just described chiefly in the fact that they are mounted on columns or posts, *post drills*, or are held to their work in the hole by grips secured in the solid coal, *grip drills*.

All the types of hand machine drills can use the twist drill described under breast augers, but the bits should be varied to suit the character of the rock. Sets of drills in lengths of 2, 4, and 6 feet, or longer if desired, are supplied with each machine, and they are attached to the feed-screw of the machine in various ways.

19. Post Drills.—The column or post on which the hand drill is mounted must be of a form adapted to the varying conditions of mining with respect to the height of the seam and the position and inclination of the holes to be drilled. In the same working place the conditions may require the column to be lengthened or shortened; and the hole may need to be drilled near the floor or at the roof, and have almost any inclination. A post that is portable, substantial, easily and quickly adjustable to any of these conditions best meets the requirements.

Several forms of posts are on the market and in common use. A very common form is shown in Fig. 18. The post *a* is provided with a sliding leg *b*, shod with an iron point *c*, which is inserted in a pick hole in the floor, or if that is soft, into a plank. This leg is easily moved out or in to approximate the length of the post to the height of the seam, and is then fastened to the stationary part of the post by iron pins *k*. There is also a small jack-screw at the top operated by the lever *d*, by which the post is secured against the roof in any convenient position. The face of the post is supplied with a series of notches *e*, for holding a cross-bar *f*, on which is supported a threaded split nut *g*, through which the

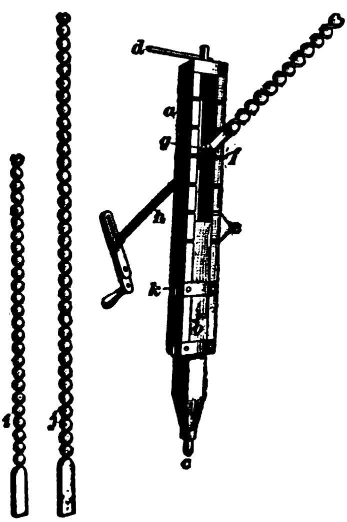


FIG. 18

feed-screw *h* of the drill passes. The post may be set as shown in the figure, with a jack-screw at the roof, and the leg in the floor when the hole is to be drilled in the upper portion of the seam; or, its position may be reversed, the leg being placed in the roof and the jack in the floor when the hole is to be drilled in the lower bench or portion of the seam. By shifting the cross-bar *f* to different notches, the inclination of the drill may be altered. After the post has been firmly placed, the crank on the end of the feed-screw is turned until the short drill has penetrated the rock a distance equal to its length. The split nut is then opened and the feed-screw returned to its original position; the short drill is then replaced by a second drill *i*. After the second drill has been run out in the same manner as the first, the operation of opening the nut and bringing back the feed-screw is repeated and a third drill *j* used, which will probably complete the depth of the hole. The twist on these drills automatically cleans the hole, but before the charge of powder is inserted a scraper usually is employed to give the hole a thorough cleaning.

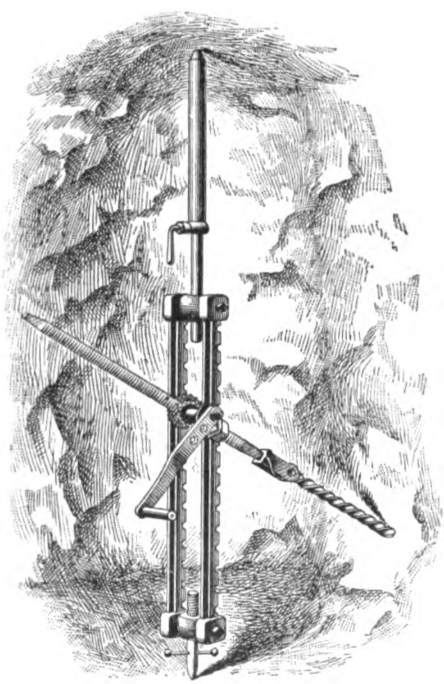


FIG. 19

Another form of this post is shown in Fig. 19, in which an adjustable pipe leg, provided with a collar and setscrew telescopes another pipe, so that the post may conform to the height of the excavation. Here the leg is placed at the roof and the small jack-screw at the floor. An adjustable pipe post is shown in Fig. 20; with the leg placed at the roof and the jack at the floor. The drill mechanism rests upon a cross-bar provided with collars that slide upon the leg, thus permitting it to be fastened to the legs by the four set-screws. This arrangement, though affording close adjustment, is perhaps not as reliable on account of wear as the series of notches employed in the post shown in Figs. 18 and 19.

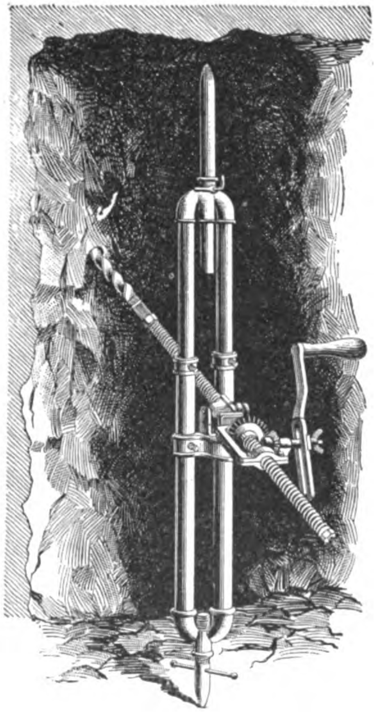


FIG. 20

20. The drill is rotated by means of a *crank*, which may be single-handed or double-handed. Fig. 21 shows a single crank whose length may be adjusted by means of a

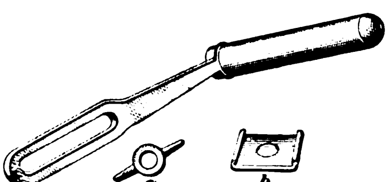


FIG. 21

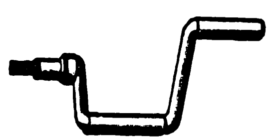


FIG. 22

slot *a*, clamp plate *b*, and nut *c*. Fig. 22 shows a double crank which permits the use of both hands in drilling.

In machine hand drills, the crank may be at the end of the feed-screw, when the machine is known as an *end borer;* or the crank may be placed at the side of the machine and rotate the drill by means of two bevel gears, when the machine is known as a *side borer.* The first of these two forms, the end borer, is shown in Figs. 18 and 19, and the second, the side borer, in Fig. 20. In the end borer the drill is rotated directly by the rotation of the crank. In the side borer the rotation of the crank causes the rotation of two beveled gears, Fig. 23, one *a* on the crank-shaft and the other *b* encircling the feed-nut. The

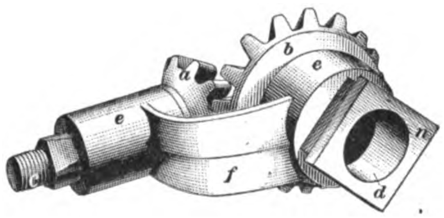


FIG. 23

crank is fastened to the shaft *c*, and the feed-screw passes through the hole *d*; the gears are held in position and rotate in the boxes *e*, *e*, firmly joined together by the frame *f*. On the interior of the gear-wheel *b* is a projecting feather, or lug, that fits into a side groove in the feed-screw, by which means the rotation of the crank and the gears is communicated to the feed-screw and the drill. As the gear *a* is smaller than the gear *b*, it requires several turns of the crank to turn the feed-screw once. In many machines these gears can be replaced, when worn, at little expense.

21. The **feed-screw,** Fig. 24, is a threaded bar 1¼ inches in diameter and from 24 to 30 inches long. According to the character of the rock or coal bored, it contains 8, 10, 12,

FIG. 24

and 14 threads to the inch, the size more commonly used being 8 and 10 threads; and feeds the drill into the hole in proportion to its speed of rotation—about 1 inch for every 8, 10, 12, or 14 turns, as the case may be. On the side of the screw a longitudinal groove *g* cuts across the threads for the entire length. In this groove slides the projecting lug, or feather, on the inner surface of the bore of the gear-wheel *b*, Fig. 23, that compels its rotation. The feed-screw is supported by a split nut, Fig. 25, which is threaded to correspond to the thread of the feed-screw. To this nut is firmly fixed two journals *a*, that form an axis for the nut and support it in any position in the notches of the column, or post. The nut is split and hinged at *c*, so that it will open and allow the removal of the feed-screw, and when closed is secured by a pin passing through the slot *d*. This threaded box, or feed-nut, advances the drill into the hole as the feed-screw is rotated. The square nut *n* of the gear frame, Fig. 23, fits into the square frame *s*, Fig. 25, thereby holding the gear frame in a fixed position with respect to the post.

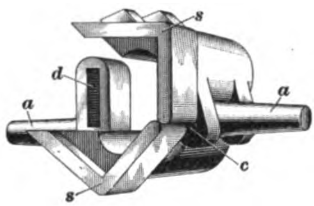


FIG. 25

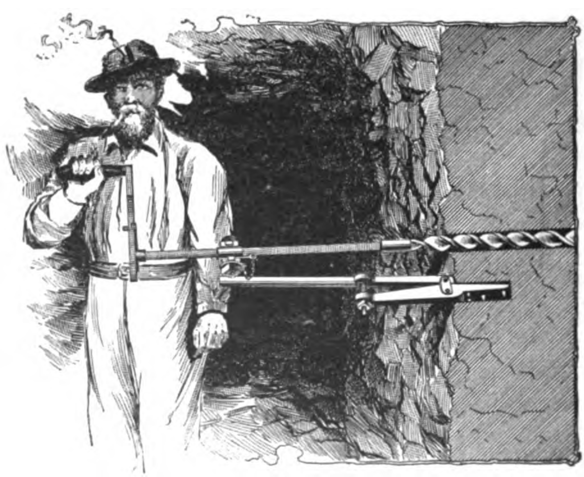


FIG. 26

22. Grip Drills.—This is a type of hand machine drill differing from the post drill only in the manner of mounting the drill. Instead of a column or post, a grip bar is employed to support the drill and the feed-screw. **Grip drills** are cheaper than post drills and are also adapted for use in places where the roof is high and where a post drill is impracticable. The method of using the grip bar for drilling is shown in Figs. 26 and 27. A short hole, about 6 inches in depth, is first drilled in the face of the coal close to the proposed hole. The end of the grip bar is placed in this hole, and made secure, Fig. 26, by spreading the tongs

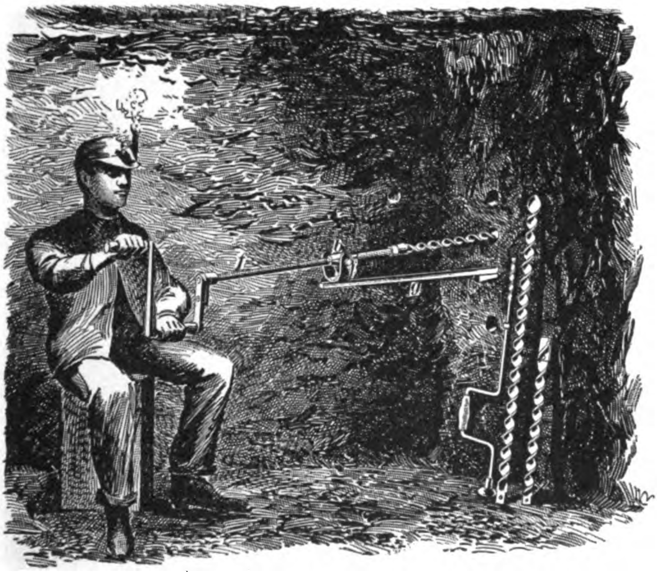


FIG. 27

at the end of the grip bar and tightening the setscrew shown in the figure.

This grip can be quickly set in place and it has the additional advantage over the grip using the wedge, Fig. 27, that it grips the rock at the back of the preliminary hole and consequently the material surrounding the grip does not become shattered, as is the case when a wedge is driven, in thus allowing the bar to fall away during the operation of drilling.

In Fig. 27 the grip bar is a simple bar with no grip tongs attached, and is made secure in the hole by driving an iron wedge below the bar. In each case the grip bar is provided with strong teeth that bite into the coal, thereby securely fastening the bar unless the coal is so soft that the wedge when driven breaks it down. The drill, or feed-bar, passes through a feed-nut mounted on an axis, or secured as described under post drills. The feed-nut support is attached to the end of the grip bar by a pivot, the arrangement being equivalent to a universal joint, and permitting any inclination or direction of the drill desired.

23. The **ratchet drill** permits the operator to place a hole close to the rib or side of an excavation, or close to the roof or floor, as illustrated in Figs. 28 and 29. In both these cases the drill is supported and held to its work by means of a post *p*, set between the floor and the roof. The feed-screw *s* of the drill, Fig. 28, is turned in a threaded

FIG. 28

nut *n* at the end of a tube *t* by means of the lever *h* operating a ratchet wheel just back of the socket holding the drill. This drill is in every respect similar to those just described, excepting that it is rotated by means of a ratchet and lever instead of a crank and gearing. The tube *t* is prevented from turning by means of a projecting pin *C*, Fig. 29, coming in contact with the post.

To set up the ratchet, a short hole is made in the proper place for drilling on the face of the rock and another in the roof back from the rock face a distance a little greater than the combined length of the shortest drill and the ratchet. One end of the post *p* is then inserted in the hole in the roof, the other end is placed upon an inclined plank, as shown,

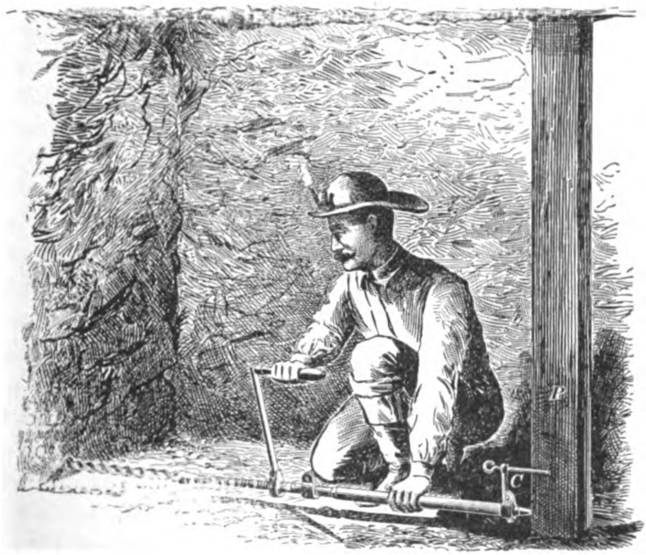


FIG. 29

and the post tightened by striking it near the bottom with a sledge. The end of the shortest drill is then put in the socket of the ratchet and the tool lifted and placed in position. The bit of the drill is then inserted in the hole made in the face of the rock. The rear end of the tube *t*, which is constructed so that it will not slip when the drill is being operated, is finally placed against the post and the ratchet and drill tightened in place by turning the tube or operating the ratchet handle *h*. When the feed-screw *s* is run out and the short drill advanced as far as possible, the ratchet is taken down and the next longer drill inserted and the operation repeated until the hole reaches the required depth. When the ratchet is used close to the rib, the drilling is necessarily slow because only one-quarter turns can be given the drill.

POWER DRILLS

24. Introduction.—The use of **power drills,** as compared with hand drills, has given a great impetus to mining work. The effect of a machine striking from 300 to 500 blows per minute, each blow being far more powerful than that delivered by any sledge or striking hammer, establishes beyond controversy the great advantage arising from their use. They are, therefore, being introduced successfully into many classes of mining work.

Compressed-air and steam drills have made it possible to work with profit many mineral lodes and veins that would be unprofitable were they developed by means of hand drilling. They have also made it possible to accomplish great engineering projects, such as the driving of large and long tunnels, the sinking of deep shafts, and the building of comparatively straight railroads in mountainous regions where deep rock cuts are required.

Like hand drills, power drills may be divided into two general classes: (1) *Power percussive drills;* (2) *Power rotary drills.* What has been said in reference to the action of these classes with respect to hand drills is likewise true with respect to power drills. The power used is compressed air, steam, or electricity. Steam is usually the most economical for drilling in outside work, except in cases where long pipes are required and in cold weather; but for tunneling and shaft sinking and mining work in general compressed air is better, for it aids in ventilating and makes the surrounding atmosphere more comfortable for the workman. Further, it is more economical to transmit air a considerable distance through pipes than it is steam. The construction of electric motors adapts them particularly to imparting rotary motion rather than reciprocating motion. Hence, electricity has at present only a limited application in the operation of percussive drills.

POWER PERCUSSIVE DRILLS

STEAM AND COMPRESSED-AIR DRILLS

25. Construction.—The construction of **compressed-air** and **steam percussive drills** is practically the same excepting in the construction of the valves and in minor details; hence a description of the one shown in section in Fig. 30 will answer for all with the exception of the valves.

The drill proper consists of a hollow cylinder *1* closed by the front head *2* and the back head *3*, which are held tight against the cylinder ends by through bolts and nuts *4*. On the top of the cylinder is mounted a steam, or air, chest *5*, in which a valve *6* moves back and forth over the steam ports shown in the illustration. The auxiliary valve *7* is a flattened crescent-shaped valve with small ports, on one side, that open and close the steam ports of the main valve but do not throw the valve by contact with it, in which respect it differs from tappet valves, even though it is moved through its slide by piston *8*. The piston is a heavy piece of metal that fits snugly in the cylinder and is moved backwards and forwards by the steam or air that alternately enters and exhausts from each end of the cylinder. One end of the piston has forged to it an extension that passes through the front cylinder head and has an enlarged end *9* termed a chuck; the other end of the piston is hollowed to receive a rifle bar *10*, which turns the piston on the back stroke, and since the drill is fastened to the chuck by the round key *11* and the chuck bolt *12*, it also turns. The rifle bar is prevented from turning on the forward stroke by the pawl *13*, which engages with teeth in the rotating ratchet *14*.

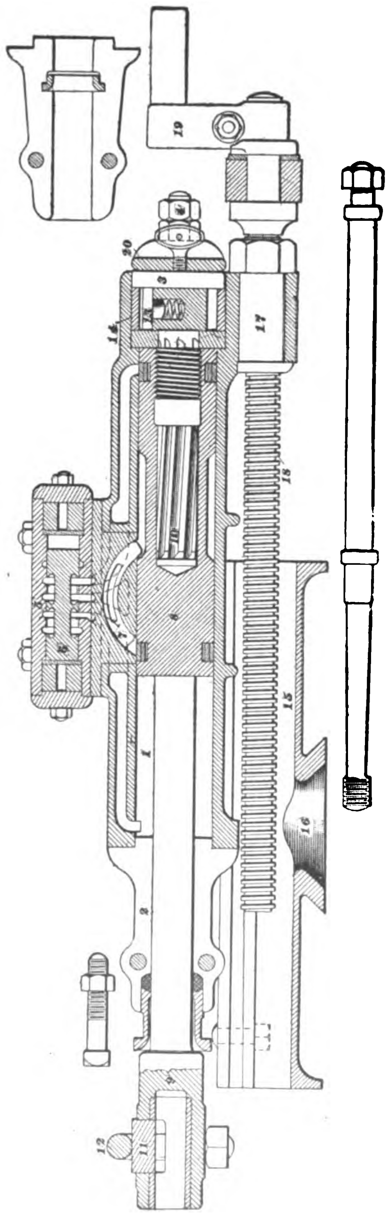


Fig. 30

The pawl and ratchet are not clearly shown in the section, but turn with the rifle bar. The cylinder is held in place by a **V** guide shell *15*, which has a cup *16*, by which it is fastened to a standard, or tripod, when at work drilling. At the back end of the cylinder is a feed-nut *17* that engages with the feed-screw *18*, having a crank *19* for the purpose of turningthe feed-screw, and thus moving forwards the cylinder, with its piston, and the drill as the latter cuts away the rock. The back head of the machine cushions against a spring *20*, and is thus prevented from being broken by the recoil of the piston in case of accidents or clogging of the valves. The split front head is used when the machine is worked with steam, and a solid front head takes its place when air is the power, unless a leather washer is used for packing the piston instead of a gland.

26. Tappet Valve.—Fig. 31 shows in cross-section a **tappet valve,** which is a valve that is thrown by the action of the piston directly and not by means of steam pressure. These valves have an advantage over steam-actuated valves since their full movement cannot be prevented by condensed steam. In Fig. 31, *a* is a three-armed lever, rocker, or tappet, that operates a **D** valve *b*. The rocker is placed in a recess of the cylinder and is held in place by a pin. The piston *c* is double-headed, and as it moves backwards and

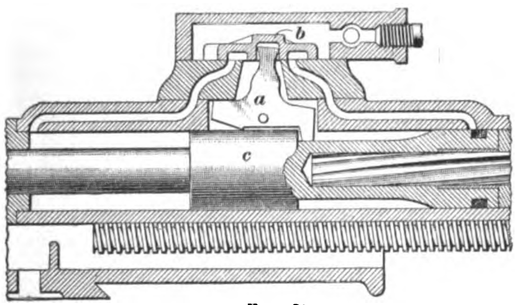


FIG. 31

forwards, its shoulders move the rocker in the direction in which it is going, and the upper arm of the tappet moves the valve in an opposite direction; this insures a positive valve motion, when steam or air is admitted, without dependence on close fits of the parts. The tappet valve allows a variation in design between the forward and backward stroke of the piston, which should economize in the use of steam, without detracting from the force of the blow. The drill having a tappet valve is called a tappet drill, but its only distinguishing feature from the drill already described is the valve movement.

27. Spool Valves.—The Wood air drill is operated by **a spool valve** that has no mechanical connection with the piston. The center spools *a*, *b*, Fig. 32 (*a*), alternately cover and uncover the ports *f*, *h*, Fig. 32 (*b*), thus allowing the air to alternately rush in at one end of the cylinder and exhaust out of the other. This movement of the air gives a reciprocating motion to the drill piston, which is governed by the movement of the valve. Two small holes *j*, *i* are in constant communication with the air pressure, and through them air is admitted by the passages *l*, *k* to the ends of the valve. These passages, or ports, *l*, *k* are alternately closed and opened by the piston in its movements, hence the holes *i*, *j* can only admit air to throw the valve from one side of the valve chest to the other when the piston is moved. It is impossible to have pressure at each end of

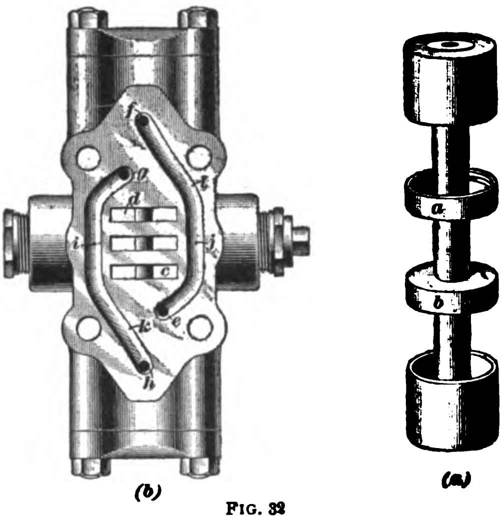


FIG. 32

the valve at the same time, or for both ends of the valve to be exhausting at the same time.

The movement of the valve is accomplished as follows: The drill piston by its reciprocating movement alternately covers and uncovers the holes *g*, *e*, and thus allows the air to pass through the holes *i*, *j* and accumulate back of the end spools of the valve and throw it first toward one end of the air chest and then toward the other; but the end spools never cross a port, hence the valve is not liable to freeze. When the drill piston covers the hole *g*, the air that has accumulated at the end *h* moves the valve to the opposite end of the air chest, at the same time the pressure that was at the end *f* escapes along the passage *l* through the hole *e*, across the cylinder through a passage not shown, and out to the exhaust. On the return stroke the drill piston covers the hole *c*; and the accumulated pressure behind the valve at the end *f* moves the valve to the opposite end of the air chest, allowing the air behind the valve at the end *h* to escape along the port *k* and pass out through the hole *g*, across the cylinder, in a passage not shown, to the exhaust.

POWER DRILL MOUNTINGS

28. Drill Tripods.—Power drills are mounted either upon a **tripod, a column,** or on a **horizontal bar.** The general appearance of a drill set up on a tripod and ready for work is shown in Fig. 33. The tripod legs, which are joined to the frame by universal joints *a*, are telescopic; that is, the upper portion is hollow while the lower portion is solid and may be pulled out or shoved in, and thus the legs lengthened or shortened. These legs may be held in any position by the collar and setscrew shown and thus made to conform to any unevenness of the ground where drilling is to be done. The weights *b* are placed on the legs to prevent excessive vibration and overcome the recoil of the drill; however, they are often not all used; the drill runners' helper standing on the clamps that support the weights takes their place. This, however, is allowable only under certain conditions and when steam is not used.

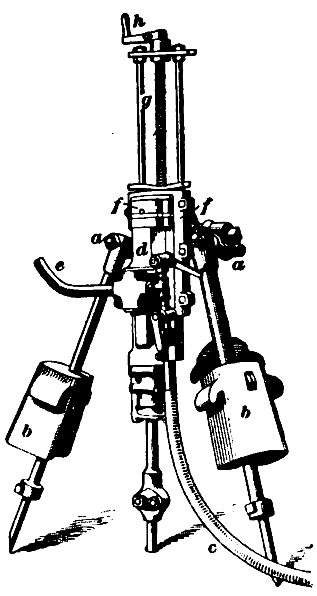


FIG. 33

In Fig. 33, *c* is the hose through which steam or air enters through the steam chest *d* to the cylinder, and *e* is the exhaust leading through the steam chest to the cylinder. The guide shell *f*, Fig. 33, has two standards, connected by a crosshead. The feed-crank *h* turns the feed-screw *g*

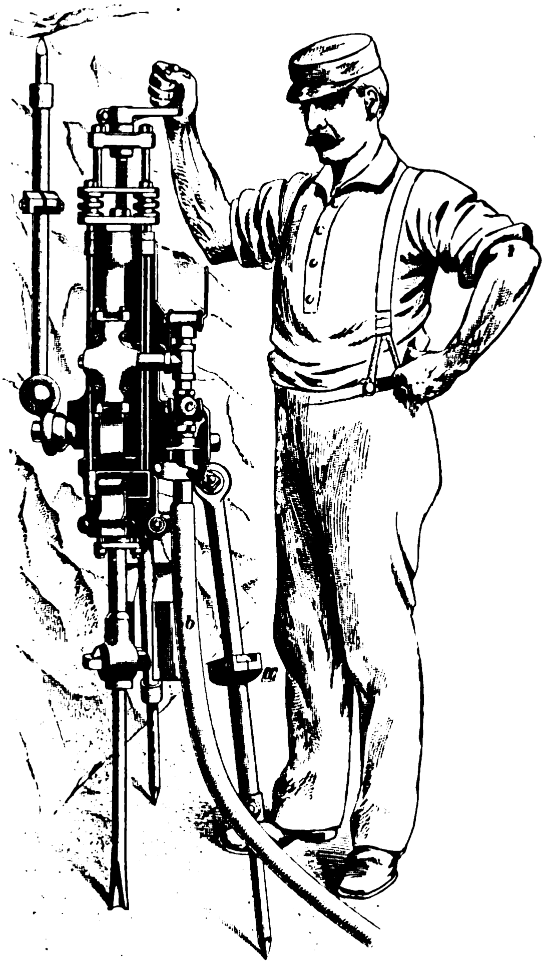


FIG. 34

and moves the drill cylinder toward or away from the hole.

For drilling a hole close to the wall, the tripod legs would be in the way if they were spread as shown in Fig. 33, but the universal joints permit their being placed in the position shown in Fig. 34, and if the roof of the excavation is not too high, the upright leg may fit tight against the wall and so steady the machine. In this illustration the clamps *a* are shown upon which the leg weights are placed, also the compressed-air hose *b* and throttle valve *c*. No exhaust pipe is shown in this illustration.

The tripod is particularly adapted for drilling holes downwards; however, it cannot always be advantageously used for drilling horizontal or upward holes.

29. Drill Columns. In tunnel driving, shaft sinking, and, generally, in mining work, it is more convenient to support the drill on a column or bar, Figs. 35 and 36, than on a tripod. These columns are hollow and are from 3½ to 6 inches in diameter, and from 4 feet to 9 feet long, though special longer sizes can be obtained if necessary. One end of the column *a* has a bearing plate that rests against a block of wood, as shown in Figs. 37 and 38, thus distributing the pressure over a greater area and forming a firmer bearing for the column than the plate alone would do. The columns are lengthened or shortened by jack-screws, which are turned by a lever placed in the holes *b*. The single-screw column shown in Fig. 35 has a bearing plate at the bottom of the jack-screw, which rests upon a

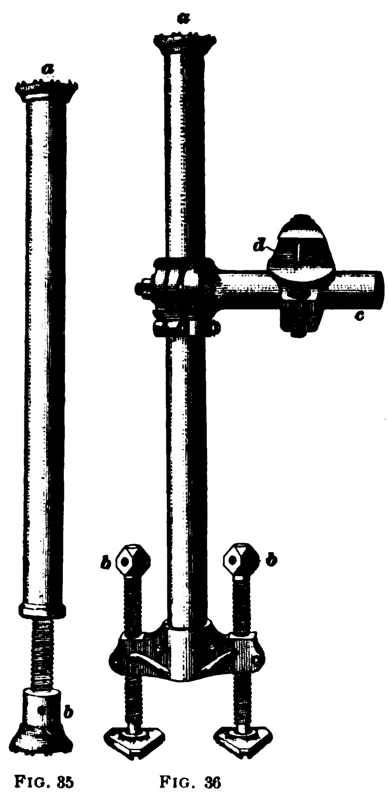


FIG. 35 FIG. 36

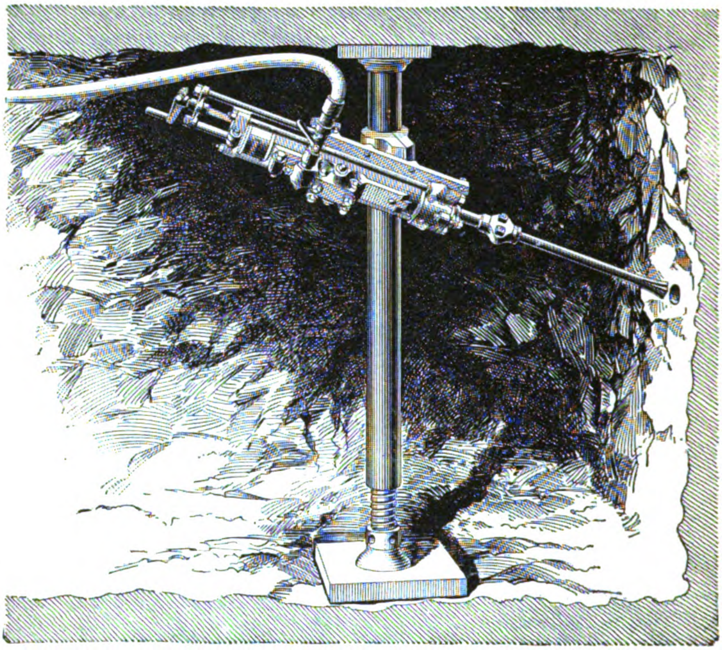


FIG. 37

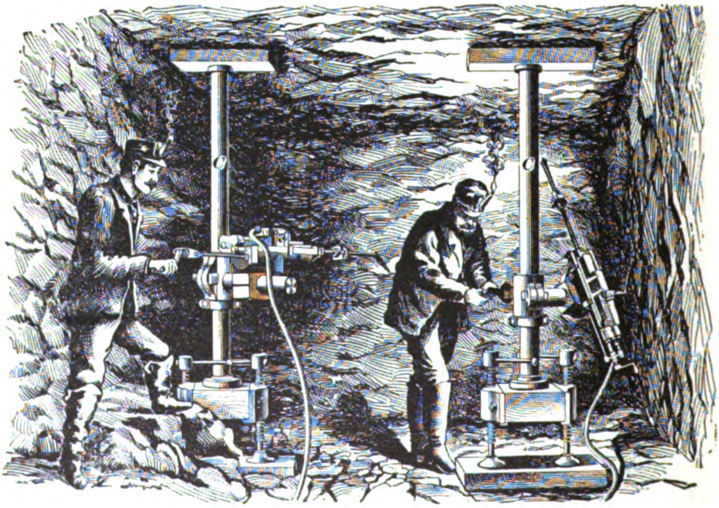


FIG. 38

block of wood similar to the bearing plate at the top of the column. In the double-screw column the screws are rounded and fitted in bearing cups, which also rest on timber pieces. A column arm *c*, Fig. 36, is clamped to the column and to this the drill is attached by the saddle clamp *d*. This combination provides a universal joint, which permits of the drill being inclined in any direction, while the column arm can be moved up and down and rotated about the column.

Fig. 37 shows a single column in place for drilling a slightly inclined hole.

Fig. 38 shows two drills, each mounted on a double-screw column *C*. The drill on the left is in position for a horizontal hole, while that on the right is being placed and the driller is shown as tightening the column clamps.

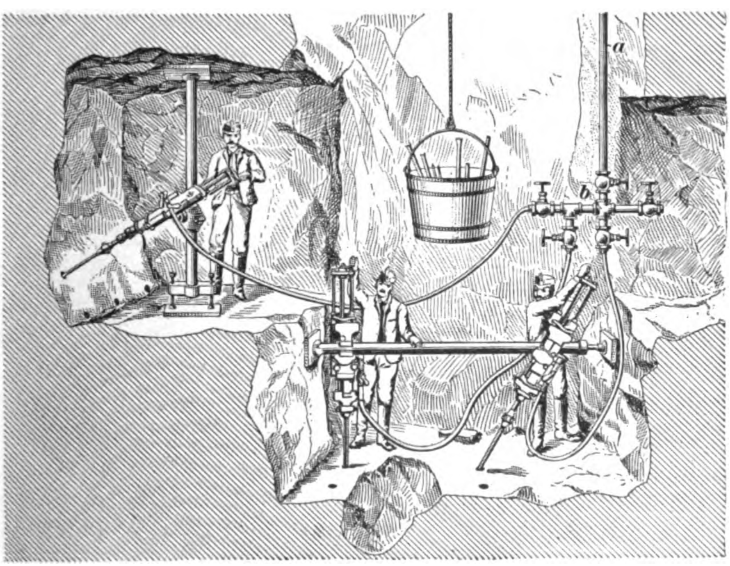


FIG. 39

30. Shaft Bars.—In shaft sinking the drill is frequently mounted on a shaft bar, which is a column placed horizontally, as shown in Fig. 39. This illustration shows the possibility of machine drills and their adaptability to sinking and drifting. On the left an undercut hole is being drilled while in the center or shaft portion, breaking and lifting holes are being drilled by two machines on the same shaft bar. All these machines are taking air from one pipe *a*, to which is attached a manifold *b*. A fourth machine could also be worked in the drift to the right.

31. Steam and Air Connections.—Figs. 40 and 41 show pieces of rubber hose termed 5-ply, that is, hose made of five reinforcement rings of cotton alternately covered with rubber. These rings give sufficient strength to the hose to prevent the steam or air stretching the rubber. Fig. 40 shows a marline-, or tarred-cord-, wound hose, the object being principally to prevent rocks cutting the hose and incidently the cord may act as a reinforcement. Fig. 41 shows a piece of wire-wound rubber hose, the wire having the same object in view as that mentioned for marline-wound hose. The usual size of hose is 1 inch in diameter, and only the marline-wound hose is advisable for steam, since heat will expand the rubber and possibly cause the wire to cut into it; besides wire becomes hot and makes hose difficult to handle. Hose for drills is made in special lengths of 50 feet each, and it is advisable to purchase it in such lengths, for while it may be unnecessarily long to start with, after it wears it can be spliced and still not be too short.

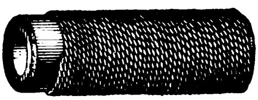


FIG. 40

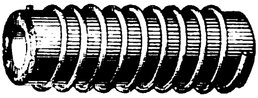


FIG. 41

A hose coupling is shown in Fig. 43, and the method of fastening the coupling to a hose in Fig. 42. The inner circle of the section shows the stem *a* of the coupling inserted in the hose. The outer end of the stem has a collar, or some other arrangement, to which the clamps *b* hold, as shown in Fig. 43; also a flange over which the nut *c* passes. Between the stem and the nut is a rubber washer for making a tight joint when the spud *d* is screwed into the nut. The spud is threaded inside to take a nipple. A

FIG. 42

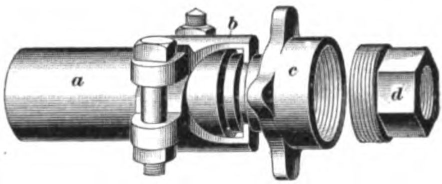


FIG. 43

set of couplings means two couplings one for each end of the hose.

32. Power-Drill Bits.—The bits of power drills are subject to greater pounding than hand drills. Hence, the drill steel used for them is harder than that used for hand drills and contains about 1 per cent. carbon. They are usually made +-shaped, Fig. 44, or ×-shaped, as shown in Fig. 45, the latter being considered better, as there is less liability of its rifling the drill hole and thus causing the drill to stick. Although the × bit is preferable, it is not as much used as the + bit on account of the difficulty in giving the cutting edges proper angles.

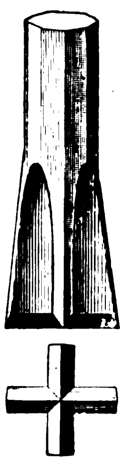


FIG. 44

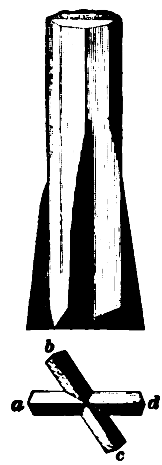


FIG. 45

Fig. 46 shows the blacksmith's tools used in sharpening and forging machine bits. The swage (*a*) is placed in the hardy hole of the anvil and is used, in connection with the spreader (*b*), to form the wings of the bit. After this is accomplished the flatter (*c*) and the sow (*d*) are used to give the bits the + shape. The dolly (*e*) is used to give the bit a proper cutting edge, and when this has been accomplished the drill is tempered.

The cross-bit dolly is shown at (*f*) and the top and bottom shank swages at (*g*) and (*h*).

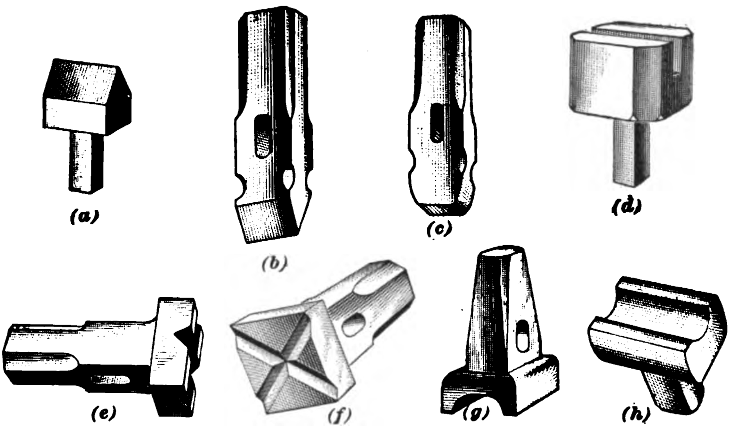


FIG. 46

In order to enlarge the diameter of the bit so as to give it proper clearance in the hole, the process known as *clubbing the bit* is used. The drill steel is first heated in the forge, then raised vertically above the anvil, as shown at *a*, Fig. 47, and allowed to drop upon the anvil. This spreads the metal, but before the proper diameter and shape is obtained, it may require several heatings. After the metal has been sufficiently spread, the bit is shaped, with a hammer and the tools mentioned, into the form desired. The last operation is forging the shank, which requires a truly made swage of the same diameter and length as the finished shank.

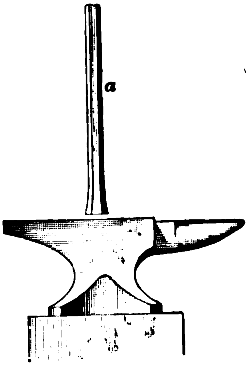


FIG. 47

33. Drill Sets.—Drills for machines are made in sets for two reasons: first, the diameters of the drill bit become gradually smaller, due to abrasion against the side of the drill hole, hence the hole would become too small if the bit were not changed frequently; and, second, because the feed-screw is only about 30 inches in the largest drill, and that limits the depth of the hole with any given drill. For example, it is desired to drill a hole 10 feet with a 15-inch feed-screw, the starter will be 2¼ inches in diameter, 15 inches long. When this is run out, 6 drills, each 15 inches longer than the preceding and each one ⅛ inch less in diameter, would follow, the last one being 8 feet 9 inches long. A set of three bits is shown in Fig. 48. The shank *a* must be forged round and straight, for if it is bent even slightly it will break at the chuck; and in more than one instance a broken piston rod has resulted from a crooked shank.

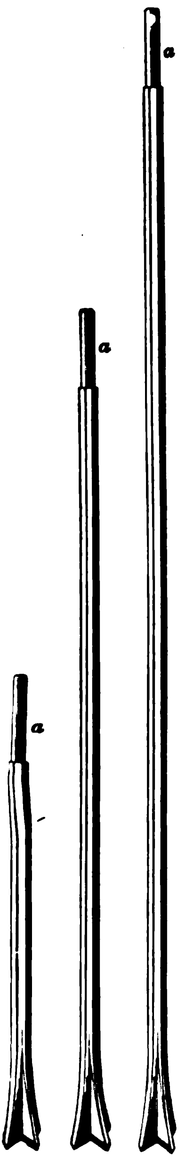


FIG. 48

USE OF MACHINE DRILLS

34. Setting Up a Drill on a Tripod. The first matter that needs the attention of the drill runner is the direction in which the hole is to be drilled to produce the best effect. The direction of the hole being decided, if a tripod is being used, a small hole is made for the point of each leg with a pole pick or hand drill and hammer. The legs are now put in the *spots* made and lengthened or shortened until the saddle is approximately horizontal, when the movable legs are securely fastened by the set-screws, and the leg weights are put in position. The machine is next placed in the tripod saddle and bolted in place, after which the saddle with machine is pointed in the direction that the hole is to be drilled and bolted in place. The starter, or shortest drill, is put in the chuck, its shank having been previously wiped to remove any adhering dirt, and the chuck-bolt nuts evenly tightened. The piston is next drawn out to the bottom of the cylinder until it strikes the cylinder head, and the feed-screw turned until the point where the bit will strike the rock is spotted, after which the piston and drill are drawn away from the face so that the point where the bit will strike may be squared off. This is particularly necessary where the rock slants or slanting holes are to be drilled, in order to prevent the shank or the piston rod bending and causing trouble. The rock should have a space a trifle larger than the diameter of the bit, squared off with a hand drill and hammer, for the machine shakes some and consequently the bit will not always strike true within ½ inch when starting. Oil is next poured into the throttle valve and into the cylinder, a matter which needs particular attention in new drills.

The machine is now ready to be coupled to the air or steam hose, but before this is done the hose should be blown out and the end wiped inside and out so that no grit will pass into the drill. The hose is next coupled to the throttle valve, that being turned off, and the machine is ready to start. It requires considerable time to set the drill up properly, but it must be done, otherwise it will cost more for repairs.

35. Setting Up the Drill on Column or Bar.—If the column, or its namesake, the shaft bar or stoping bar, is to be used, pieces of plank must be placed between the rock and each end, as the column will not always hold without this precaution. The column bar is held in place by setting out the jack-screws firmly, and with the shaft or stoping bar, the locknut on the screw is also tightened. The bar being in place, the drill is placed in its saddle and fastened in the direction the hole is to be drilled. As a usual thing, the column arm and clamp are adjusted before the drill is mounted upon them, although after this has been done they may need some slight readjustment. The hole is pointed and the drill coupled to the hose with the same precautions observed as when using the tripod.

36. Starting the Drill.—Before the drill is started all bolts and nuts should be tightened, and the side rods screwed down evenly, but no more than to make air-tight or steam-tight joints at each end of the cylinder. When starting a hole, the throttle valve should not be opened more than half way, and not until the hole is from 5 to 8 inches deep should it be opened wide; the hole should be kept partially filled with water, the quantity depending on the stiffness of the mud made. Some rock cuttings mixed with water become so stiff that they stop the drill and must be removed by a sludge pump When the starter has cut as deep as it will, it is replaced by the next longer drill in the set. In case a spool valve does not move freely, tap lightly on the center of the valve chest; in case this does not have the desired effect, it may be taken for granted that some of the ports are closed and need cleaning out. If the steel gets stuck in the hole and cannot be started with a light pound, the drill is probably not in line with the center of the hole. This may be due to a bent drill shank, a bent piston rod, or the drill mounting having slipped, in any case the matter must be remedied, and probably the first step to take is to loosen the clamp the guide shell sets in and ascertain if the drill is in line with the hole. In no case should the drill be struck with a sledge; it may cause a bent drill shank or bent piston rod. A slight tap on the chuck is sufficient to loosen the drill if the cylinder is in line with the center of the hole. If there should be a broken pawl spring take it out and replace it, or if necessary run with one pawl, until it can be replaced.

37. Care of Steam Drills.—When a new machine is to be started with steam, trouble will be sometimes experienced from the refusal of the machine to start. This arises from the unequal heating of the cylinder, and will disappear as soon as the machine becomes uniformly heated. To hasten the heating and discharge the water of condensation, proceed as follows: Arrange the machine on the tripod and set the drill point in the direction the hole is to be drilled, then loosen the nuts on the long through bolts so as to relieve the cylinder heads. Now turn on a small quantity of steam. The water of condensation will run out between the cylinder and head, and presently steam will commence to blow through and warm the machine. Work the piston in and out, by hand, two or three times, so as to have the steam blow out first at one end and then at the other. Presently, when everything is well heated, the machine will start off all right, and the nuts at first loosened should be gradually tightened. When learning to run a machine, it is advisable to use steam at low pressure—say 30 pounds per square inch. When accustomed to it, the pressure can be increased to 60 pounds or more. It is also an excellent plan to run a new machine with a blunt-pointed steel—simply striking the rock without cutting it—until it is well "limbered up" and the gum of the old oil thoroughly removed.

In cold weather do not leave water in the cylinder; unscrew the stuffingbox and let it out, otherwise it may freeze and crack the cylinder.

POWER-DRILL SPECIFICATIONS

38. André sums up the requirements of a good percussive machine rock drill as follows:

1. It should be simple in construction and strong in every part.

2. It should consist of few parts and especially of few moving parts.

3. It should be as light as possible consistent with strength.

4. It should occupy as little space as possible.

5. The striking part should be of relatively great weight, and should strike the rock directly.

6. No parts except the bit and piston should be subject to violent shocks.

7. The piston should have a variable stroke.

8. The sudden removal of the resistance should not cause any injury to any part.

9. The drill should be rotated automatically.

10. The feed, if automatic, should be regulated by the advance of the piston as the cutting advances.

39. Weight of a Power Drill.—The weight of a steam or compressed-air percussive rock drill, less the weight of the piston and drill, should be greater than the total steam and air pressure upon the piston head, for it is its pressure that reacts upon the machine and tends to lift it when the piston is being forced downwards. It is to overcome this reactionary force that the dead weights are placed upon the legs of the tripod. When the machine is attached to a drilling column, dead weights of course are not required, the column compensating the reactionary force.

If the size of a piston head of the machine rock drill is 3 inches in diameter, and the steam or air pressure be taken at 70 pounds per square inch, the constant force that accelerates the piston and weight will equal $3^2 \times .7854 \times 70 = 494.8$ pounds. Hence, the weight that tends to keep the machine in place while the piston is being forced out should be at least 500 pounds, otherwise the reactionary force will move the machine in the same way that a cannon recoils when a large ball is shot from it.

40. Power-Drill Dimensions and Other Data.—The following are the average dimensions and features of the power percussive rock drills:

1. The diameter of the piston varies from 2 to 5 inches.

2. The length of a stroke varies from 4½ to 8 inches.

3. The extreme length of the drill from the end of the feed-crank to the end of the piston varies from 36 to 60 inches.

4. The length of the piston, or the distance the piston and cylinder can be moved to follow up the advance of the hole, varies from 12 to 30 inches.

5. The weight of the machine without the tripod varies from about 100 to 700 pounds. The weight of the tripod without the dead weights varies from 40 to 270 pounds. The total weight of the machine varies from 250 to 1,600 pounds.

6. The force of the blow varies from 250 to 1,500 pounds.

7. The mean steam or air pressure used is 60 pounds per square inch.

8. The average number of strokes per minute for small drills is 500, and for large drills 300.

9. The large machines drill to a depth of approximately 30 inches, and the small machines to about 12 inches without changing bits.

10. The average work done in drilling downward holes in granite is about 7 feet per hour.

11. The depths to which the small and large machines drill holes are about 4 and 30 feet, respectively.

12. The diameter of the holes drilled by small and large machines are from $\frac{5}{8}$ inch to $1\frac{1}{2}$ inches and from 3 to 6 inches, respectively.

13. The diameter of the steel bars used for making drills for small machines varies from $\frac{3}{4}$ to $\frac{7}{8}$ inch; and for large machines from $1\frac{5}{8}$ to $2\frac{1}{2}$ inches.

14. The number of drills that make a set depends on the length of the feed and the depth of the hole desired.

15. It requires about 5 horsepower to work the small drills and from 15 to 25 horsepower to work the large ones, according to the diameter of their cylinders and the length of their strokes.

ELECTRIC DRILLS

41. Introduction.—For a number of years inventors have endeavored to perfect a percussive electric drill, but to the present time no one has succeeded in replacing the compressed-air or steam drills, except in particular locations where it is almost impossible to work the latter. The chief difficulty encountered is that an electric motor does not produce an effective direct reciprocating motion. The great weight of many of the electric drills is another of their most objectionable features. Inventors have worked on widely different lines, so that in one case there is a drill with a reciprocating piston worked by electricity termed a *solenoid drill;* in another, the motor and drill are separate, the latter receiving power for drilling through a flexible shaft; and again, the motor is combined with the drill in such a way that a hammer is made to strike the blow.

In general appearance the electric drill resembles a steam or air drill; it is similarly mounted on a tripod, column, or bar, and can be used any place where explosive gases are not present in excess.

42. Solenoid Electric Drill. — Electric drills of the Marvin type depend for their operation on two coils of wire, each wound in the form of a spiral or helix, through which an electric current is passed first in one direction and then in the other. If a steel core be passed through these two adjacent coils and a current run through one of them, the core will be drawn in one direction; if the current then is run through the other coil, the core will be drawn in the opposite direction, thus forming a machine that will give a forward and backward motion and producing, in effect, the same motion that is produced by steam or compressed air acting alternately on opposite ends of a drill piston.

Fig. 49 shows a longitudinal section of a solenoid drill in which a solid steel piston *a* is surrounded at each end by a coil of wire *b*, *c*. The shank *s* of this piston passes through a front head resting on a brass bushing *l*, as shown. The end of the plunger, or piston, is provided with a solid chuck for holding the drill steel. The change of current from one coil to the other is affected at the dynamo and hence there is no necessity for current-shifting devices. The coils *b*, *c* are made of square-sectioned wire and are peculiar to this machine. The bare copper wire of each square section is insulated, as it is wound, with pure mica, no other insulation being used in the construction of the drill. The wire is wound upon a steel tube provided with steel heads and is encased in an iron jacket, making the coil impervious to dirt and moisture. The shape of the wire and the material applied for insulation enables the coil to be wound so that when completed it is practically a solid mass of copper and mica that is insulated from the steel tube and the heads of the machine.

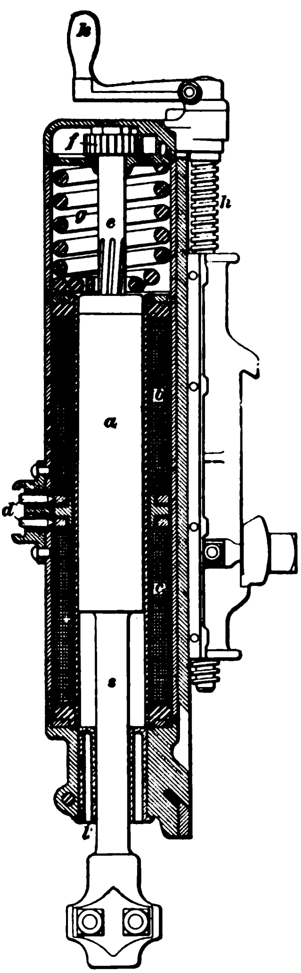


FIG. 49

The piston on its forward stroke does not turn on the rifle bar *e*, but does on its backward stroke, the ratchet *f* being held in place by a pawl that prevents its turning on the forward stroke. This arrangement prevents the drill on the forward stroke from striking consecutively in the same place in the hole. The large spring *g* is termed a *cushion spring*, its function being to check the backward stroke of the plunger, and in doing so it absorbs the surplus energy of the return stroke and supplies the energy thus stored to the forward stroke. The front and back heads are held in place similarly by bolts that pass along the sides of the drill case. The feed-screw *h* in the guide shell moves the machine forwards as the crank *k* is turned. In case the bit meets with no resistance and the stroke becomes excessively long, the plunger is prevented from striking the brass bushing *l* by a magnetic force set up in the rear coil. The plunger runs quite freely, having no stuffingboxes, but simply having a bearing in the coils and in the front head of the drill. It is not necessary that the brass bushing fits the shank closely, as the machine runs quickly and without any loss of efficiency when this bearing of the plunger is so badly worn as to leave it with a great amount of play, the only requirements of the bearings being to hold the plunger somewhere within a central position so that the bit does not wabble too much in starting a hole.

43. The construction of this drill is such that it can be easily taken apart and put together by any one with ordinary ability. A specially made generator is designed for this apparatus and the drills run at the same speed as the dynamo. Each revolution of the dynamo armature produces one complete stroke of the drill. The current is led from the dynamo to the drills over independent circuits made with three copper wires, one wire, usually the middle, being common to both circuits. The wires are led from the dynamo to a point conveniently near the drills, and the current then taken to them by means of flexible cables of any desired length, usually about 100 feet. Several drills may be operated from one set of wires, provided the wires are of sufficient size and carry the required amount of current. It is generally desirable to carry three wires from the generator to the center of the mine and then run separate branches to the separate parts of the work to which the cables may be attached at any time. The low pressure used in operating these drills—about 135 volts to each drill—prevents any possibility of injury to the men; in fact it is customary where these drills are used for the workmen to feel of the wires to find out whether the current is flowing or not. One of the advantages claimed for this drill is the low horsepower that it uses and its flexibility, it being much easier to carry the force around in wires than in pipes, also that the power may be generated by means of water at some distance from where the drills are to be used. A list of the sizes and weights of the drills is given in the annexed table.

TABLE II

SPECIFICATIONS FOR MARVIN DRILLS

Name of Drill	5-Inch Drill	6-Inch Drill	7-Inch Drill	8-Inch Drill
Outside diameter of case..	5 in.	6 in.	7 in.	8 in.
Length of drill over all....	43 in.	45 in.	50 in.	53 in.
Length of stroke.........	5 in.	7 in.	8 in.	8 in.
Weight of plunger........	25 lb.	55 lb.	65 lb.	80 lb.
Length of feed...........	20 in.	24 in.	24 in.	30 in.
Usual depth of hole drilled	3 ft.	8 ft.	15 ft.	20 ft.
Usual size of hole at bottom	1⅛ in.	1½ in.	1¾ in.	2 in.
Horsepower applied to dynamo pulley............	4 H.P.	6 H.P.	8 H.P.	10 H.P.
Weight of machine without mounting..............	180 lb.	300 lb.	395 lb.	480 lb.
Weight of tripod without weights................		150 lb.	180 lb.	200 lb.
Volts at the drill..........	135	135	135	135
Amperes.................	15 to 25	20 to 30	30 to 45	45 to 50

NOTE.—The number of strokes per minute is regulated according to the character of the rock, but is usually 380.

44. The Flexible-Shaft Electric Drill.—Figs. 50, 51, and 52 show the Gardner electric drill that has recently been introduced into the western part of the United States. The electric current in this case does not enter the drill itself, which is separated from the motor *b* and connected with it by a flexible shaft *a*, Fig. 50, but the power is delivered to the bit by means of a crank that is revolved by beveled gears that receive their motion through the flexible shaft. The drill weighs from 150 to 315 pounds, according to the size, and is mounted either on a tripod or column.

The electric motor runs ordinarily at a speed of 1,800 revolutions per minute and is geared by means of a phosphor-bronze pinion and a cast-iron gear to what is termed a *jack-shaft*. This cast-iron gear drives the shaft by means of two fiber friction disks on either side of the hub; the pressure for friction grip being produced by a spring that is set at sufficient tension to drive the drill under normal conditions; but should the drill still stick in the hole and prevent

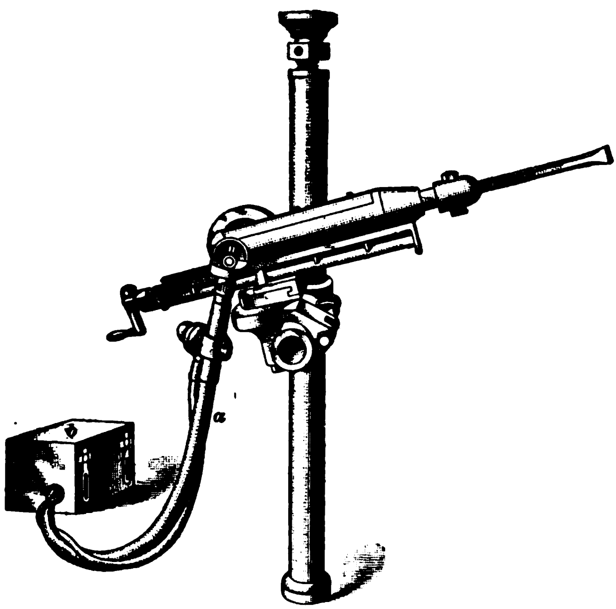


Fig. 50

rotation of the flexible shaft, the cast-iron gear will slip and thus prevent serious damage to any part of the mechanism. The power is transmitted from the jack-shaft at the motor through the flexible shaft to a pair of miter gears *a*, Fig. 52, at the crank-shaft of the drill. This crank-shaft having a roller on the center crankpin *a*, Fig. 51, transmits power to a drawbar *b*, in which is a cam-slot *c* so designed as to give this drawbar a relatively quick forward stroke and a slow

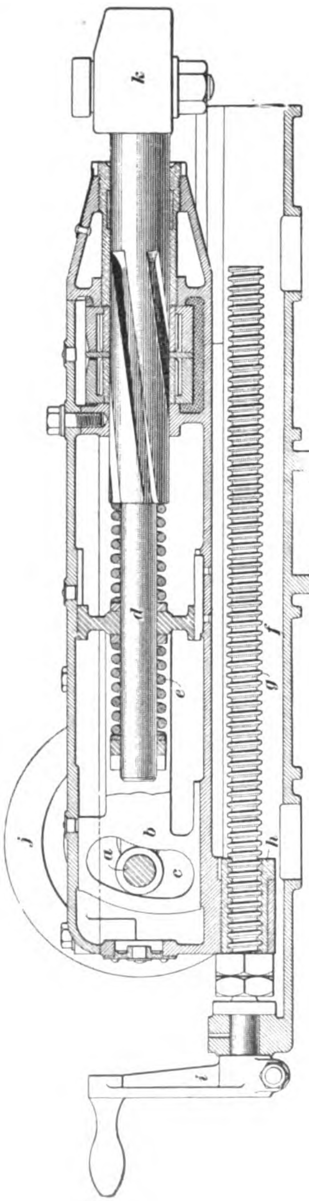


FIG. 51

return. This bar transmits power to the plunger *d* through spiral springs *e* that are of sufficient strength to strike a blow necessary to cut rock, at the same time these springs are useful in forming a cushion, as the drill can be run while not striking rock without serious damage to the machine. The rotation of the drill is affected by means of ratchet wheels located in the forward part of the body of the drill, but not well shown in the illustration. In the plunger, there are straight grooves that engage the corresponding ratchet wheel for guiding the piston straight during the forward stroke, and the spiral grooves that engage the corresponding ratchet wheel for turning the drill on its backward stroke. Fig. 51 shows the guide shell *f*, the feed-screw *g*; the feed-screw nut *h*, and the feed-screw crank *i*. There is a fly-wheel *j* on the crank-shaft of the drill to steady the movement of the machine. The chuck *k* does not materially differ from those described. The smaller drill requires a 1½ horsepower motor, which weighs about 175 pounds. This drill will cut holes to 5 feet in depth with a 2-inch bit, and strikes about 600 blows per minute. The length of the stroke is stated to be 2¼ inches and the force of the blow about 200 pounds. The larger drills have a 2½-horsepower motor, which weighs about 200 pounds. This drill starts with a 2½-inch bit and cuts holes 8 feet in depth, striking 500 blows per minute.

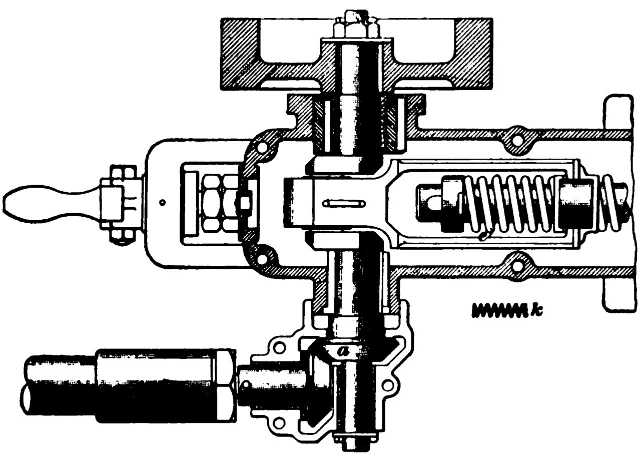


FIG. 52

The weight and general construction of these drills is to their advantage in handling, but the heavy motor that must be carried around detracts from this in a measure. It is claimed that these drills are much cheaper to operate, and that from 6 to 8 Gardner drills can be operated with the same amount of power that is required to operate one air or steam drill. It is claimed further that one drill will do the work of from 8 to 10 men with hammers.

45. Box Electric Drill.—The **Box electric drill** is a recent invention. In the design of this drill the inventor has endeavored to avoid the weak points which experience has shown exist in other electric drills, with the result that several new features appear, making it radically different from other percussive drills. The power for

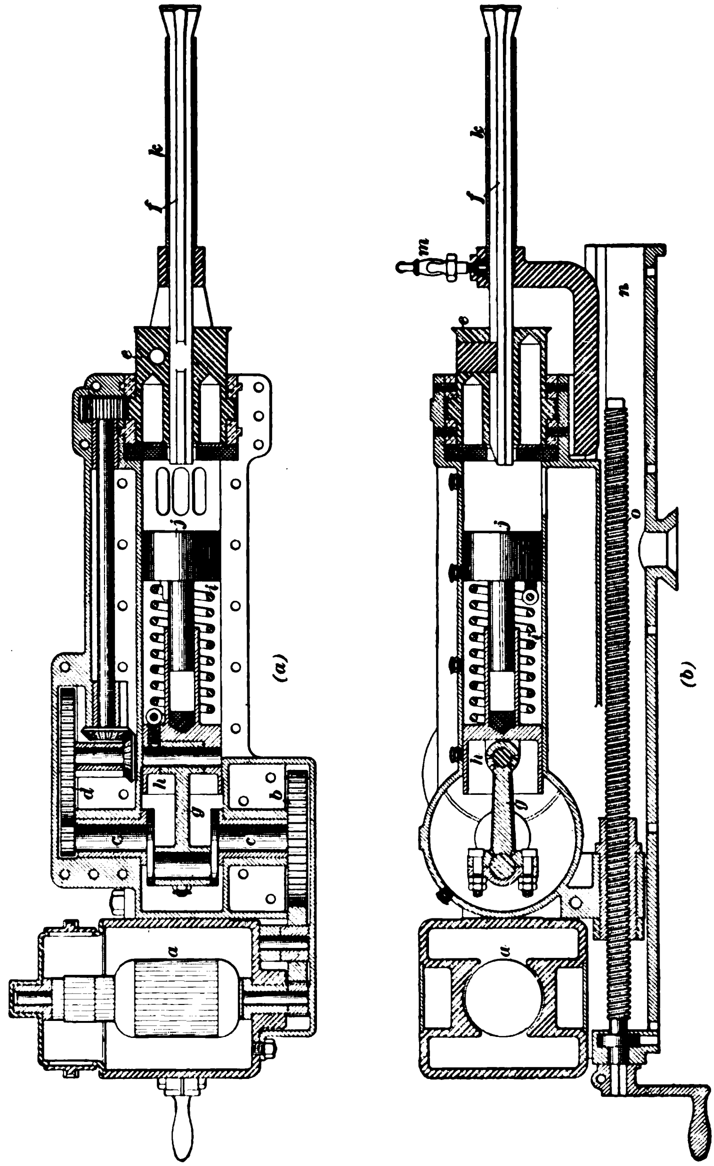


FIG. 53

driving the drill is supplied by a small electric motor *a*, shown in Fig. 53 (*a*) and (*b*) On the armature shaft of the motor is a pinion that forms a train with the gear *b* on the crank-shaft *c*, thereby causing that shaft to rotate. At the other end of the crank-shaft is a pinion that drives the gear-wheel *d*, and this in turn drives other gears and shafts, as shown in Fig. 53 (*a*), for the purpose of transmitting rotary motion to the chuck *e*.

There is a connecting-rod *g*, which imparts reciprocating motion from the crank to the hollow crosshead *h*, and thus to the hammer *j* that strikes the drill steel *f*. The hammer and crosshead are connected by a spiral spring *i*. In order to permit the drill bit to cut rock freely, water is allowed to flow into the drill hole through the tube *k*. A valve *m*, Fig. 53 (*b*), is fitted to the frame of the machine, and to this a rubber hose leading to the water-supply connection is attached. The **V** guide shell *n* and feed-screw *o* are similar in their action to those previously described for other drills. The entire mechanism is enclosed in a steel casing, so there is no danger of the operator's fingers or clothing becoming caught, or of dirt and dust reaching the moving parts. The drill may be worked either from a tripod or column and have the same adjustments as the air drill.

46. The principle of applying vibration to rock drilling is a new idea, yet this is accomplished in the Box drill with apparent satisfaction. The striking action of the hammer is based on the principle that if a weight is suspended from a rubber band held by the hand and the hand is moved up and down, the weight will also move in a similar manner, but through a greater range, owing to the elasticity of the rubber. In this drill the hammer represents the weight, while the coiled spring is the substitute for the rubber band. The crosshead moves very fast, and the hammer with the same velocity, thus accomplishing the same result as heavy pistons in other drills moving with comparatively slow velocity. When the hammer strikes the drill, the shock or recoil is taken up by the spring and is not transmitted to the machine in the same manner as in other drills; this permits the drill to run smooth and without jar.

47. The weight of the Box drill with motor is 350 pounds. When the motor is removed, the drill and guide shell weigh 250 pounds, which weight compares favorably with air drills having a 3-inch piston. The makers claim that, where a solenoid electric drill requires 7 horsepower, and a flexible-shaft electric drill requires 2.5 horsepower, this drill requires 1 horsepower for the same work. There are no heavy reciprocating parts, as they are not needed when the hammer and drill steel are separated, and the drill chuck is stationary. The drill steel may be easily removed and another substituted without unscrewing and screwing up chuck bolts, an item which saves considerable of the driller's time. One firm considers that this fact, and the ease with which the drill can be mounted and unlimbered, saves them an hour a day. There is no danger of the machine being damaged if the feed is too fast or too slow, as the striking mechanism is independent of the drill steel. There is perfect control of the speed, with constant and uniform rotation of the steel, thus producing a round straight hole without fitchering. The wear on drill steel should not be as great as in other drills that are usually turned by rifle bars, ratchets, pawls, etc., as the drill moves back and forth. No special steel is required for this drill, and the machine is not noisy.

By means of the water tube the drill is pointed correctly, and any movement of the machine will not break a shank or injure the drill, before it is noticed; it further permits an easier centering of the machine after movement. The water is also delivered at the bottom of the hole, thus washing away the rock particles as soon as they are cut. The simple method of holding the drill steel in the chuck is not shown in the illustrations given, but has decided advantages over the ordinary chuck keys, U bolts, and nuts, as the chuck block that holds the drill is hinged and made fast by a pin, thereby lessening the time necessary for changing drills and doing away with repairs at this point.

ROTARY POWER DRILLS

48. Compressed-Air Augur Drill.—Fig. 54 shows a **rotary power drill** driven and fed by compressed air. The small rotary engine that drives the drill is placed between the prongs of the drill post and above the supports, which hold it in any desired position. Instead of such a feed-screw as is used on hand drills, a piston rod in the cylinder *a* is acted on by the air and forced outwards as the hole is advanced. The small pinion on the motor shaft gears internally with the wheel *b*, which turns the piston rod

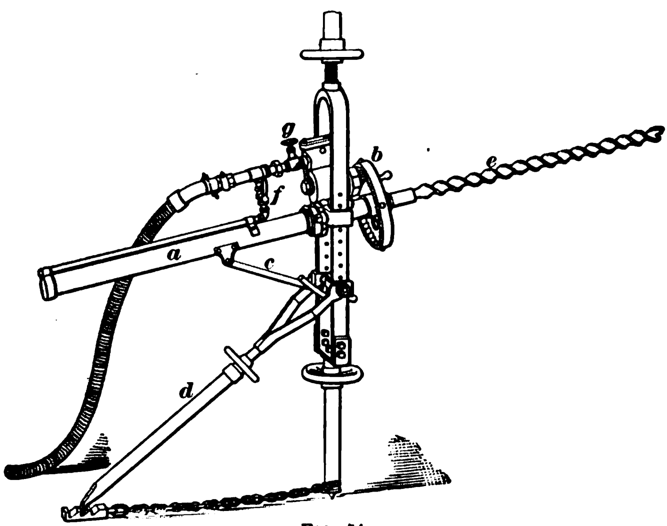


FIG. 54

and auger *e*. It is clear that while the wheel *b* turns the auger, it also permits it to move longitudinally. This is accomplished by means of a feather and slot; the slot extends the entire length of the feed-screw, while the feather is stationary in the hub of wheel *b*. Without this arrangement the feed-screw would not turn with the wheel *b* and feed forwards through a feed-nut. The brace *c* supports the extra weight at the rear of the post, and the brace *d* makes the post more rigid. The auger can be advanced with a constant pressure, and therefore the bit is not likely to break when it meets any hard substance. The air is admitted to the cylinder *a* through the valve *f*, and to the rotary engine through the valve *g*. The drill is supported on a frame or post similar to that used with hand drills, only stronger.

49. Electric Auger Drill.—Fig. 55 shows a Jeffrey **electric auger coal drill.** A small motor of from 1½ to 4 horsepower, enclosed in a case, has on the end of its armature shaft a small pinion that gears with the large wheel *b*. The current is supplied through the cable *c*. The drill can be given an elevation and clamped at various levels by the

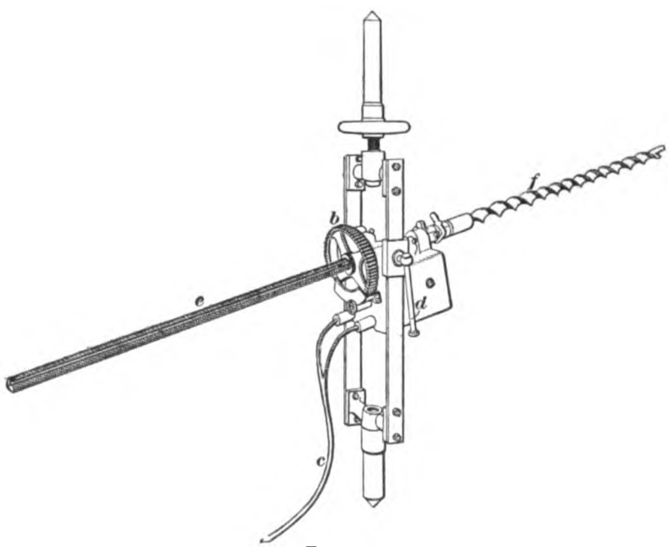


FIG. 55

lever *d*. A longitudinal slot in the feed-screw *e* receives a feather, or projection, on the gear-wheel *b*, which regulates the number of revolutions of the feed-screw and drill *f*. Two drill bits or augers are used for each hole over 3 feet deep; one is 3 feet long and the other 6 feet. The time required to drill a 6-foot hole in ordinary bituminous coal with this drill is from 1 to 14 minutes.

TEMPERING AND DRESSING STEEL

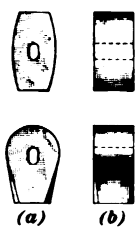
50. Commercial Forms of Iron.—The three forms in which iron occurs commercially are *cast iron*, *steel*, and *wrought iron*. There is no exact line of division between these three forms, as each one grades gradually into the next, although the amount of carbon that each form contains may be considered as the principal element that distinguishes it. Cast iron contains the highest percentage of carbon, usually over 3 per cent., is brittle and very slightly elastic and ductile. Wrought iron is the purest form; it contains very little carbon, usually only from .02 to .01 per cent., and is tough and ductile. Steel is intermediate between cast iron and wrought iron, both in the amount of carbon that it contains and in its properties, and no absolute definition of it can be given. Much of the material that is now known as low-carbon steel has practically the same composition of what was formerly called wrought iron.

Although carbon is the principal element combined with the iron and is the principal ingredient that distinguishes the different varieties of iron, and also the different varieties of steel, there are several other elements, principally sulphur, phosphorus, manganese, and nickel, that while they may be called impurities in the iron or steel, exert a great influence on its quality. Sulphur renders iron or steel red-short, or brittle, when heated. Phosphorus renders iron or steel cold-short, or brittle, when cold. A small amount of manganese renders steel both tougher and harder, while a small amount of nickel increases both the tensile strength and the ductility of steel.

51. Drill Steel.—In order to make a good percussive drill, it is necessary to have special steel, known as *drill steel*, which must be tough when hardened and must not be too brittle. A moderately high-carbon steel containing an .8 to 1 per cent. carbon is generally used, provided the steel does not contain impurities that will make it brittle; a very fine tool steel will not answer for rock drilling, as it chips too easily. Drill steel is generally octagonal or round in shape and is furnished in lengths of 6, 8, and 10 feet and varies in diameter from ½ inch to 2 inches, the sizes most commonly used being from ¾ inch to 1 inch in diameter. Smaller sizes than this are too elastic, and larger sizes are too heavy for ordinary work, except for starters.

52. Dressing the Bit.—The tool dresser should understand that wrought iron can be converted into steel by carbonization and steel into iron by the oxidation of a portion of its carbon. For example, if a piece of wrought iron is buried in powdered charcoal and the air kept away from it, the skin of the iron becomes carbonized and converted into steel; and if on the other hand a bar of red-hot steel is buried in oxide of iron, the skin of the steel becomes decarbonized and is converted into a malleable steel or possibly wrought iron. In the same way, if the cutting edge of a bit is made red hot in the forge fire and kept at that heat for some time, it will be decarbonized and converted into mild steel. Hence care should be exercised in heating the drill bits. In shaping tools, blows should not be heavier than is necessary for the required work; they should be glancing, so as to draw the fibers of the steel toward the cutting edge of the bit.

For sharpening drill bits any straight peen hammer that has a smooth face will do; but if there are many tools to be dressed, it is better to have either of the blacksmith hammers shown in Fig. 56 (*a*) and (*b*). Blacksmith coal and charcoal are the best for forge work; however, any coal that contains but a small amount of sulphur, produces little clinker and ash, does not splinter or fly, and gives a solid fire that will reach over the piece being forged, may be used. The bit and a small portion of the shank should be well bedded in the coals, when heating, to prevent oxidation and loss of carbon, which will soften the iron and render it unfit for use. The heating must be



(*a*) (*b*)

FIG. 56

uniform and gradual, for which purpose the drill is turned over in the fire so that it may become heated to the center. When the shank of a drill is heavy, compared with the bit, it should be subjected to the stronger heat in the fire so that the heating will be uniform and more easily controlled. When the proper heating has been obtained the drill is withdrawn and tapped lightly, or brushed off, to free it from any adhering cinder. The smith, then, with a few light, dextrous blows shapes the cutting edge.

If the corners of the bit are badly worn, it will perhaps be found necessary to upset the edge at the center to give the bit its proper width; this is done at a fair heat. The smith then holds the drill at an angle of elevation of about 45°, and placing the edge of the bit even with the edge of the anvil, Fig. 57, strikes a series of light, glancing blows, turning the bit over from time to time. This serves to draw the fibers and toughens them, giving a better edge to the tool. The edge may then be dressed with a file if desired before tempering. It is important to remember that the blows of the hammer must not be too heavy; the lighter the blows, the tougher will the steel be rendered.

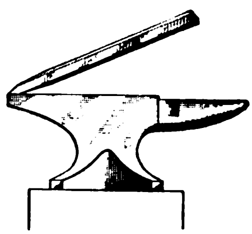


FIG. 57

In dressing the bits of a set of drills, care should be taken in regard to the width of the bit, that each successive length of drill be made a trifle narrower than the preceding length in order to enable it to enter the hole made by the other drills when slightly worn.

53. Temperature of Heated Iron. — Table III will be of interest as giving the approximate temperature and corresponding color of heated iron from dark red to the melting point.

The dark redness of iron heated to 1,000° F. is barely visible in bright daylight, but plainly visible in twilight or dark.

TABLE III

Temperature Degrees Fahrenheit	Degree of Heating
700	Just visibly red in dark
1,000	Just visibly red in daylight
1,300	Dull red
1,500	Scarlet
1,650	Cherry
1,850	Bright cherry
2,000	Dull orange
2,200	Bright orange
2,400	White
2,550	Brilliant white, welding heat
2,820	Dazzling white, melting point

54. Tempering Steel.—After the drill bit has been properly shaped, it is tempered; that is, it is given the hardness necessary for the work which it is to do. This is accomplished by reheating the drill and cooling. Steel should not be heated harder nor longer than is necessary, as there is danger of burning it; that is, oxidizing the carbon in the steel and thus changing its quality. It is not safe to heat high-carbon steel, such as drill steel, above dull redness and never above cherry red, or a crystalline brittle structure may develop during tempering. A piece of steel properly tempered should always be finer in grain than the bar from which it was made. If it is necessary, in order to make the piece of necessary hardness, to heat it so hot that after being hardened it will be as coarse or coarser in grain than the bar, then the steel itself contains too little carbon for the desired work, and is said to be burned.

55. Heat Colors of Steel. — When steel is slowly heated, its surface gradually changes in color, due probably to the formation of a fine film of oxide on the surface. The colors that thus successively appear from a low to a higher temperature are a yellowish-white or light-straw color, a dark-straw, gold or yellow, brown, purple, violet, and deep blue. Finally, the steel becomes red hot and a black oxide is formed. These colors are deeper and more distinct the better the quality of the steel, and are often scarcely perceptible in very poor steel. The practiced eye of an expert steel man determines with great accuracy the quality of the steel by the depth of the colors. Whatever their cause, these colors indicate important changes that are taking place at different temperatures in the hardness of the steel, and furnish a reliable guide in the tempering of steel to any required hardness. Now, if the order be reversed and a piece of steel be first heated to low redness and then allowed to cool, the same colors will be observed upon its surface in the reverse order, the blue first appearing, then the purple, brown, yellow, straw, and white, as the metal cools. If the changes that are taking place in the metal can be suddenly arrested by cooling the steel at any given point, the steel will acquire permanently the hardness and character corresponding to such temperature. This is done by suddenly plunging the steel into a cold bath of either water or oil, etc. When a drill bit that has been submerged and cooled in this manner is withdrawn from the bath, the reserve heat in its shank travels by conduction toward the bit, raising its temperature gradually to that of the shank, and producing a flow of colors, Fig. 58, down the tool, starting from the point to which the steel was cooled and disappearing at the cutting edge.

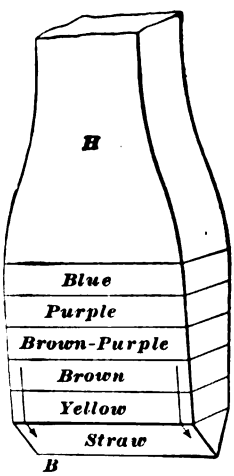


FIG. 58

56. The following experiment will enable a person to familiarize himself with the several colors appearing on the surface of the steel and the hardness of the steel corresponding to these colors. Take an old table knife and lay it on a very hot stove or very hot iron, presently the blade will show a straw color that will move toward the handle, this will be followed by a yellow, then a brown-yellow, a brown-purple, purple, and blue in quick succession. The degree of hardness corresponding to the different colors may be learned by placing the blade flat upon the hot iron so that its entire length will be of the same temperature and color at the same instant. When the blade becomes straw color plunge it quickly into the water and then test its hardness with a file. Repeat the operation for the different colors, and when the work is complete the experimenter will have a very good knowledge of the degree of hardness that corresponds to the different colors for the particular quality of steel in the knife blade. In the same way a blacksmith learns the degree of hardness that corresponds to the various colors of each grade of steel that he has to work or dress for bits.

Table IV gives the temperature corresponding to the several colors that form upon the surface of bright-tempered steel when heated to dull redness and then allowed to cool. This table is given as an illustration of what is done in the tempering of different kinds of steel for different purposes, and will serve as a helpful guide in the tempering of different grades of tool steel. It must not be supposed, however, that certain grades of steel will not take a higher temper than that indicated in the table. This will depend much on the character of the work, the use or handling the tool receives, and the experience of the workman. For example, it is not uncommon for picks to be tempered at a brown, or hard-coal drills to be tempered at a yellow, although in such case the tools require careful and experienced handling to avoid breaking the bit.

Not only is it important that one who tempers drills should know the temperatures indicated by the different colors, but one should also know that colors will vary for different qualties of steel. For example, with a fine quality

TABLE IV

Temperature Degrees Fahrenheit	Colors	Tools Tempered
430	Very pale yellow	Lancets
450	Pale yellow	Razors, metal engraving tools
470	Full yellow (straw)	Knives, hammers, punches, taps, dies, cold chisels (steel)
490	Brown	Hatchets, scissors, drills (rock and hard coal)
510	Brown, with purple spots	Axes, planes, picks (hard coal), tools (copper)
530	Purple	Wood-turning drills, picks (soft coal)
550	Bright blue	Springs, augers
560	Full blue	Cold chisels (soft iron and copper)
600	Dark blue	Spiral springs, hand saws

of cast steel a temperature of 490° F., corresponding to a brown color, would give a bit when cooled at that temperature a cutting edge suitable for drilling in rock of average hardness; but with a comparatively mild steel having from .5 to .6 per cent. of carbon a temperature of 530° F., which corresponds to a purple color, would be required to attain the same hardness and toughness.

PRACTICAL POINTS IN TEMPERING

57. In tempering a drill bit the following points should be observed:

1. When the bit is plunged in water, it should be moved up and down, or the molecular tension above and below the

water-line will be so different that the bit will be liable to break in the same way as a glass when hot water is poured into it.

2. The drill bit should not be heated in the incandescent cinders of a fire, as that will decarbonize and render the cutting edge worthless.

3. The bit should be heated a few inches back from the cutting edge to prevent decarbonization, and it should not be kept in the fire longer than necessary to heat it to a cherry-red color.

4. Immediately after removing the bit from the fire it should be plunged in water for a moment to partially cool it and then should be rubbed on a stone to remove the outside scale in order that the colors may be easily distinguished.

5. The colors should advance parallel to the cutting edge; and if in any case they are observed to do otherwise, that portion of the bit to which they are advancing most rapidly should be held in water. Frequently it is necessary to plunge the bit in water several times to obtain the proper parallelism before the final cooling; if the bit were cooled when the colors were not parallel to its cutting edge but crossed it, the cutting edge would likely be too soft in one place and too brittle in another.

58. Tempering in Oil.—The drill bits are more serviceable when tempered in thick oil or cold tar than when tempered in water. It is presumed that this is due to the water rapidly chilling the thin parts and the skin of thick parts, thus producing uneven hardness in the bit while oil or tar cools the bit more gradually and thereby renders it more tough. If it is found that a certain bit should be dipped in water when it has a blue color, it should be dipped in oil when it has a purple color; in other words, to produce the same degree of hardness with oil that has been obtained by water, the bit should be dipped in the oil when it has the color that precedes the one that it had when dipped in water. In nearly all cases steel is made tougher and more uniform when tempered in oil than when tempered in water.

59. Annealing, or Softening.—The process of **softening** iron or steel by heating to redness and slowly cooling is called **annealing.** The proper heat for annealing steel is a bright cherry red; but as high-carbon steels are apt to assume a slightly crystalline structure at this heat, their annealing heat should be somewhat lower. Drill steel may be safely annealed from a dull-red to a cherry heat. The toughness and softness of the steel increase with the slowness of the cooling. Ashes, being a poor conductor of heat, are often used for covering the hot steel when annealing, so that it will cool slowly. Sometimes the cooling is done in the air, in which case the surface of the metal is decarbonized and toughened, but the steel is not as soft, as all the annealing effect is produced while the steel is cooling to a point just below visible redness.

60. The **quenching bath** is generally a large tub or tank of water of sufficient size to allow the cooling to be done rapidly and without danger of raising the temperature of the bath; otherwise, the hardening of the steel will not be accomplished in a thorough manner. Some of the baths commonly used, given in the order of their rate of cooling, are brine, water, rape-seed oil, tallow, and coal tar. Soapy water cools still more slowly than clear water. As previously explained, in the use of any bath cooling more slowly than another, the steel must be plunged enough earlier to secure the same temper, since the condition of the steel changes continually until arrested by quenching.

In the use of oil, for tempering, there is a certain amount of carbon absorbed by the surface of the hot iron, which thereby becomes slightly carbonized and toughened as well as hardened.

An oil bath smokes slightly when steel is tempered at the yellow, stronger and darker smoke is produced when tempering at the brown, and heavy black smoke at the purple. The oil begins to light when tempering at the full dark blue, but does not burn continuously. When hot steel is plunged into a bath it must be moved about quickly to prevent a line of fracture being formed in the steel at the surface of the liquid; the motion also increases the rate of cooling.

61. Specifications for Drill Steel.—That portion of the drill which fits into the piston chuck varies according to the size of the drill. This shank is made of certain diameter and length, for example,

TABLE V

SIZE OF SHANK OF DRILLS

Diameter of Drill Inches	Size of Shank Inches	Diameter of Drill Inches	Size of Shank Inches
2	$\frac{5}{8} \times 3$	3	$1\frac{1}{8} \times 5\frac{1}{2}$
$2\frac{1}{4}$	$\frac{3}{4} \times 3\frac{1}{2}$	$3\frac{1}{8}$	$1\frac{1}{8} \times 6$
$2\frac{1}{2}$	$\frac{7}{8} \times 4\frac{3}{4}$	$3\frac{5}{8}$	$1\frac{3}{8} \times 6\frac{1}{2}$
$2\frac{3}{4}$	1×5	$4\frac{1}{2}$	$1\frac{1}{2} \times 7$

The steel usually employed is octagonal, although the weight per foot in the accompanying table is given for round steel as well. In arriving at the weight of steel required for a drill, $\frac{1}{2}$ pound is to be added to compensate for the enlargement of the bit. The number of drills in a set will depend on the length of the feed-screw and the depth to which the hole is to be bored; for example, with a 12-inch feed it would require four drills for a 5-foot hole, but only three when a feed-screw is 15 inches. In each case each succeeding drill is 12 or 15 inches longer than the one preceding, and this length must be followed to correspond with the length of the feed-screw. The starting drills are made of heavier steel than the ones following, for the reasons that the heaviest work comes on them; and the hole must be of larger diameter at the start, since it will grow smaller in diameter the more depth it has. Ordinary drill holes are not much over 6 feet, but at times holes 25 feet deep may be needed; as the bits wear, each succeeding bit is made smaller and the blacksmith must gauge the diameter of bits for the depth of hole to be drilled. Usually each succeeding bit is made 1/8 inch in diameter smaller than the preceding.

TABLE VI

WEIGHT OF DRILL

Round		Octagonal		Round		Octagonal	
Size Inches	Weight Pounds	Size Inches	Weight Pounds	Size Inches	Weight Pounds	Size Inches	Weight Pounds
1/8	.04	1/8	.04	1 5/8	7.05	1 5/8	7.32
3/16	.09	3/16	.10	1 3/4	8.18	1 3/4	8.64
1/4	.17	1/4	.18	1 7/8	9.38	1 7/8	9.92
5/16	.26	5/16	.28	2	10.71	2	11.28
3/8	.38	3/8	.40	2 1/8	12.05	2 1/8	12.71
7/16	.51	7/16	.54	2 1/4	13.60	2 1/4	14.24
1/2	.67	1/2	.70	2 3/8	15.10	2 3/8	15.88
9/16	.85	9/16	.89	2 1/2	16.68	2 1/2	17.65
5/8	1.04	5/8	1.10	2 5/8	18.39	2 5/8	19.45
11/16	1.27	11/16	1.33	2 3/4	20.18	2 3/4	21.28
3/4	1.50	3/4	1.58	2 7/8	22.06	2 7/8	23.28
13/16	1.76	13/16	1.83	3	24.10	3	25.36
7/8	2.04	7/8	2.16	3 1/8	26.12	3 1/8	27.50
15/16	2.35	15/16	2.48	3 1/4	28.30	3 1/4	29.28
1	2.67	1	2.82	3 3/8	30.45	3 3/8	32.10
1 1/8	3.38	1 1/8	3.56	3 1/2	32.70	3 1/2	34.56
1 1/4	4.17	1 1/4	4.40	3 5/8	35.20	3 5/8	37.05
1 3/8	5.05	1 3/8	5.32	3 3/4	37.54	3 3/4	39.68
1 1/2	6.02	1 1/2	6.34				

EXPLOSIVES AND BLASTING

MINING EXPLOSIVES

INTRODUCTION

1. Definition.—An **explosive** is a single substance or mixture of substances capable of being suddenly, and more or less completely, transformed into a large volume of gaseous products by the application of heat or shock, or both. The result of the chemical action, when an explosive is ignited, is the sudden production of a large amount of gas at a very high temperature. This gas exerts such enormous pressure on the sides of the space confining the explosive that it breaks and shatters them.

2. Chemical Action of Explosives.—With explosives composed of a mixture of substances, the gaseous products are formed by the combination of certain of the constituents with the oxygen contained in other constituents; black powder is a good example. Some of the most sensitive and violent explosives contain no oxygen whatever (as for example, nitrogen iodide); these explosives are definite chemical compounds and the explosion is due to a rearrangement of the atoms and a breaking down of the molecule into more stable gaseous products. In many other explosives, which are also definite chemical compounds but contain oxygen, such as nitroglycerine, guncotton, etc., the breaking down of the molecule may be considered an internal combustion of the carbon and hydrogen of the molecule.

3. The **force of an explosive**, whether a single chemical compound or a mechanical mixture of compounds depends: (1) on the suddenness with which the gases are liberated; (2) on the amount of gases liberated; (3) on the temperature developed by the explosion. In combustible explosives, the rapidity of the combustion varies greatly according to the kind of explosive, the rate of combustion in black powder being 6 inches to 13 feet per second, while that of nitroglycerine may exceed 16,000 feet per second.

According to the composition of the explosive, this chemical action may be: (*a*) A comparatively slow-burning and spitting of flame, known as *deflagration*, in which the heat that ignites the substance is transmitted, by conduction, from particle to particle comparatively slowly. (*b*) An almost instantaneous transformation and interchange of atoms known as a *detonation*. This decomposition is due largely to shock and is transmitted with great rapidity by a wave of compression that affects the entire mass almost simultaneously.

4. **The volume of the gaseous products** varies with the character of the powder and the conditions under which it is exploded. For example, 1 volume of gunpowder exploded under conditions similar to those in practice yields from 175 to 200 volumes of gases at ordinary temperature and atmospheric pressure. The solid products resulting from the explosion occupy slightly more than one-third of the original volume of the explosive, and the gaseous products somewhat less than two-thirds, which gives the relative volume of the gases with respect to the actual volume of the hole they occupy, as from 260 to 300 volumes.

This 300 volumes of gas is all confined in the 1-volume hole where the tendency to expand causes a pressure. This is assuming that the gases are at the ordinary atmospheric temperature, but in reality the temperature is much higher and consequently causes a much higher pressure on the retaining walls.

5. **The theoretical temperature** of the combustion, as calculated from the chemical equation expressing the reaction

that takes place in the explosion, can only be realized when the confining walls are absolutely unyielding. When rupture takes place before the full force of the explosive is developed, expansion follows and the temperature of the explosion is thereby reduced; this is particularly the case in blasting coal. In rock blasting, the confining walls being more unyielding, the temperature of the explosion is higher than when blasting coal. The temperature of combustion for most of the explosives varies from 5,000° F. to 6,000° F. In blasting coal with black powder, the temperature of explosion does not much exceed 2,000° F., owing to the slow combustion of the powder and the yielding nature of the coal, giving an expansion due to the heat of the explosion equal to five times the volume of the gases produced. Assuming the relative volume of gases produced as 300 at atmospheric temperature, the total expanded volume of the gases under these conditions is $5 \times 300 = 1{,}500$; that is, 1 volume of blasting powder under ordinary conditions of blasting coal, yields 1,500 volumes of gases at the temperature of the explosion. Also, 1 volume of nitroglycerine produces, when exploded, practically 1,300 volumes of gas at ordinary temperature, or about 16,000 volumes at the temperature of combustion (5,954° F.). Under ordinary conditions in practice, therefore, black powder may be assumed to be capable of 1,500 expansions in blasting coal, and possibly 2,000 in blasting rock, while nitroglycerine is capable of 16,000 expansions.

In the use of detonating explosives, there is a period of extreme cooling following the explosion and rupture of the walls. As a result, the high initial temperatures of these explosives are not maintained a sufficient period of time for the ignition of firedamp that may be present in the vicinity of the blast. Nitroglycerine, with an initial temperature of combustion of 5,954° F., is cooled by expansion of the gases to 1,792° F.

6. **The initial force of the explosive**, or the force developed at the moment of explosion, is proportional to the number of expansions of which the powder is capable, and is equal to the atmospheric pressure multiplied by the number of expansions. Thus, calling the atmospheric pressure at sea level 14.7 pounds per square inch, nitroglycerine will develop a ruptive, or bursting, pressure of $\frac{14.7 \times 16,000}{2,000}$ = 117.6 tons per square inch, while blasting powder under ordinary conditions of blasting coal will only develop $\frac{14.7 \times 1,500}{2,000} = 11.02$ tons per square inch.

7. The **mechanical work** of which any explosive is capable is estimated by multiplying the volume of gases produced in explosion by the atmospheric pressure. For example, assuming that nitroglycerine is capable of 16,000 expansions, each cubic inch of nitroglycerine is capable of doing $16,000 \times 14.7 = 235,200$ inch-pounds, or 19,600 foot-pounds of work.

The stored energy of an explosive in blasting is only partially converted into mechanical work, some of the heat of combustion being lost, by conduction, in the material enclosing the explosive.

8. Classification of Explosives.—Explosives may be classified, according to their action, as *low*, or *deflagrating*, *explosives*, and *high*, or *detonating*, *explosives*. Explosives may also be divided, according to their composition, into nitrate mixtures, chlorate mixtures, nitric derivative compounds, nitro-substitution compounds, Sprengel explosives, fulminates, etc. Explosives are also designated, with respect to the flame produced by them in exploding, as *flaming* and *flameless explosives;* in mining practice, the latter are often called *safety explosives*. Explosives used for army and navy purposes give off little or no smoke and are known as *smokeless powders*.

LOW EXPLOSIVES

9. Low explosives are comparatively slow in their action, giving a rending rather than a shattering effect. In composition, they are nitrate mixtures, and consist of intimate mixtures of a combustible substance, such as charcoal, sulphur, lampblack, sawdust, etc., with a nitrate. Potassium nitrate or saltpeter (niter), sodium nitrate (Chili saltpeter), and barium nitrate are most commonly used. Potassium nitrate does not absorb moisture as does sodium nitrate, and hence, the potassium-nitrate powders do not deteriorate as rapidly when exposed to moisture as do the sodium-nitrate powders; these latter powders are, however, very efficient explosives if kept stored in a dry place, are much cheaper than the potassium powders and are more extensively used.

Barium nitrate does not absorb moisture as readily as sodium nitrate, but it is expensive, and its action in powder is slow. It is used mainly in the manufacture of fireworks, owing to its green flame.

The principal explosives belonging to the class of nitrate mixtures are *gunpowder* and *blasting powder*, which are both frequently referred to as *black powder*.

GUNPOWDER

10. Gunpowder was one of the first explosives ever used. It consists of an intimate mechanical mixture of potassium nitrate, charcoal, and sulphur in the following proportions, by weight:

	Parts
Potassium nitrate, KNO_3	75
Charcoal, C	15
Sulphur, S	10
Total	100

The potassium nitrate furnishes the oxygen for the combustion of the carbon and sulphur, resulting in the production of a large volume of heated gases. The theoretical reaction of the explosion is represented by the chemical equation $2KNO_3 + 3C + S = K_2S + N_2 + 3CO_2$, the proportion of ingredients being such that the carbon is entirely burned to carbon dioxide. Other much more complex equations are given by some authors to represent the chemical changes taking place in an explosion of gunpowder.

11. The products of the explosion of black powder are quite variable, being greatly modified by the conditions under which the powder is exploded and they seldom correspond with the theoretical equation. The solid residue remaining after the explosion occupies about one-third of the original volume of the explosive and consists chiefly of the sulphate, carbonate, and sulphide of potassium. Besides this solid residue, 1 volume of black powder exploded will yield, as stated in Art. **4,** about 200 volumes of gaseous products at 32° F. and atmospheric pressure. The following is an example of the gaseous products of combustion for fine-grain gunpowder.

	Parts by Volume
Carbon dioxide, CO_2	50.62
Carbon monoxide, CO	10.47
Nitrogen, N	33.20
Hydrogen sulphide, H_2S	2.48
Marsh gas (methane), CH_4	.19
Hydrogen, H	2.96
Oxygen, O	.08
Total	100.00

Some of these gases are poisonous and others, while not poisonous, are suffocating and will not support life. For this reason, after firing a charge of powder in a mine, it is necessary to wait a few minutes for the gases to be diluted by the air.

12. The temperature of ignition of gunpowder varies from 600° F. for the finest grades of sporting powder, to 528° F. for rifle powder, and 518° F. for blasting powder.

While the temperature required to ignite black powder is not great, the heat due to the chemical reaction producing the explosion may, under favorable conditions, raise the temperature of the gases and solids resulting from the explosion to 5,000° F., or even 6,000° F., causing an expansion of about twelve times the volume of the gases produced, or 12 × 300 = 3,600 expansions.

13. The **specific gravity** of individual grains of gunpowder varies from 1.5 to 1.85; but in bulk, loose powder slightly shaken is about that of water, or the weight of 29.2 cubic inches (frequently given as 30 cubic inches) of gunpowder will average 1 pound. These figures are, of course, only approximate, as the gravity of powder in bulk depends on the size of the grains and how closely the grains are shaken together.

BLASTING POWDER

14. Ordinary **blasting powder** contains the same constituents as gunpowder but in different proportions; it was designed to obtain the same power at a lower temperature of explosion. This quality is secured, but the products of combustion contain much more carbon monoxide than results from gunpowder. As this gas is poisonous and inflammable, blasting powder is a dangerous explosive to use in fiery mines or in mines that are not thoroughly ventilated so that the gases from the explosion are rapidly carried away.

The composition of blasting powder is variously given as

	Parts	Parts	Parts
Potassium or sodium nitrate	65	67	66
Sulphur	20	14	11
Carbon (charcoal)	15	19	23
Total	100	100	100

The following is an analysis of the gases resulting from an explosion of blasting powder.

	Per Cent. by Volume
Carbon dioxide, CO_2	32.15
Carbon monoxide, CO	33.75
Nitrogen, N	19.03
Hydrogen sulphide, H_2S	7.10
Marsh gas (methane), CH_4	2.75
Hydrogen, H	5.22
Oxygen, O	.00
Total	100.00

15. Special Powders.—The large number of special powders made by different manufacturers for particular purposes have distinctive trade names. **Judson powder,** also known as railroad powder from its frequent use in connection with railroad work, is similar to black powder but it contains nitroglycerine, sodium nitrate, and soft coal. **Carbo-azotine** and **pyrolithe** are two of the special nitrate blasting powders designed to produce less carbon-monoxide gas than ordinary blasting powders.

CARBO-AZOTINE	Parts	PYROLITHE	Parts
Potassium nitrate	70	Potassium nitrate	51.5
Sulphur	12	Sodium nitrate	16.0
Lampblack	5	Sulphur	20.0
Sawdust	13	Carbon (charcoal)	1.5
Green vitriol	2	Sawdust	11.0

16. Safety Powders.—Gunpowder and blasting powder, which are the chief explosives used in America for blasting coal, are not now permitted in most of the English coal mines, and in their place **safety,** or **flameless, explosives** are used. These safety explosives give out only a small flame, and one that lasts for a short time only, and they are permitted in Great Britain only when it has been proved that they will not explode firedamp under certain prescribed conditions. The extinguishing of a flame is produced in these explosives largely through the use of chemicals that contain water of crystallization, which is given up when the powder explodes.

The conditions at many American coal mines, as regards explosive gases and dust, have not required the use of flameless explosives in the past, but in certain sections of the country these explosives are now being used in limited quantities. With increased depth of working, however, the conditions permitting the use of gunpowder and blasting powder will probably change and require a much more general use of the so-called flameless explosives.

17. Black-Powder Cartridges.—As the ordinary black powder for mining purposes is in grains, it is impossible to put it into most drill holes unless it is confined in cartridges, which are usually cylinders of manila paper. These cylinders are made by the miner by rolling the paper around a wooden cartridge bar of a slightly smaller diameter than the drill hole and about 18 inches long. The loose edges of the paper are stuck down by means of miners' soap (a material containing considerable pitch), one end of the paper is folded over to close the end of the cartridge, and the stick removed, leaving a paper cylinder. When the cylinder is filled with powder, the cartridge is completed by folding down the other end.

Gunpowder and blasting powder are furnished the miner in sheet-iron *kegs* holding 25 pounds. Both of these powders are fired by ignition from a fuse, squib, or electric cap. Great care should be exercised in filling a cartridge from a powder can to be away from a naked light, as the dust will very readily carry the flame into the can and explode the powder.

18. Tests of Gunpowder and Blasting Powder. The chemical determination of the ingredients of a powder should be undertaken only by a chemist, but certain physical tests that can be easily applied will give a rough idea of its quality. These tests are as follows:

To test for moisture, which may be absorbed by the saltpeter, rub the grains of powder on a piece of clean white paper; if the paper is blackened, moisture is present.

If good dry powder is ignited on a sheet of paper, it should burn quickly without burning the paper or leaving any considerable coloration on it. If the paper is burned, it is usually an indication of the presence of moisture. Black spots on the paper indicate an excess of charcoal or imperfect mixing of the ingredients. Yellow spots on the paper indicate an excess of sulphur.

The glaze on powder is given it to prevent the absorption of moisture; but this glaze detracts from the value of the powder as it delays the ignition. Loss of glaze may indicate improper storing. The grains should be hard and when broken should show a close texture and an ashen-gray color. This examination should be conducted with a magnifying glass and if large white specks are visible it indicates that the powder has not been properly mixed.

19. Handling Black Powder.—A person having black powder in a mine should not open his can until he has placed his lamp not less than 5 feet from the explosive and in such a position that the air-current cannot convey sparks to it. Powder should not be stored in the mine, but in a magazine outside erected especially for the purpose.

20. Storage of Gunpowder.—In moderately dry air, gunpowder of good quality will absorb from $\frac{1}{2}$ to $1\frac{1}{2}$ per cent. of water, and in damp air will absorb a much larger proportion, hence the necessity of storing in a dry magazine. The construction of the powder house should be such that air will circulate below the floor. The magazine should be well ventilated, but so arranged that the ventilating apparatus may be closed on rainy days. The powder house should not stand in the shade, or tight against earthen or rock banks. The powder is put up in 25-pound canisters that should be placed on their sides, and stacked in tiers rather than on their flat ends one above the other. This will permit the air to circulate around the kegs, and at each end. A good plan is to make the house large enough to hold two cars of powder, or 1,600 kegs, and afford ample room for moving about inside. The construction of the house may be entirely of wood, sheathed with sheet iron. The kegs should not be thrown about but handled with care, and only one man should be allowed inside the powder house at a time. Fuses and caps should not be stored in this building; and if lightning rods are placed on it, they must have sure ground connections with water, otherwise they are worse than none. No iron tools should be used in the magazine, and the floor nails should be sunk into the flooring so that their heads will not project. In case a keg becomes broken or powder is spilled on the floor, a wooden scoop and a broom brush should be used to clean it up. It is dangerous to walk on powder with shoe nails, for which reason the floor should be kept absolutely free from loose powder.

21. Powder Laws.—The handling and storage of explosives is regulated by law in many states, the following being the chief requirements of these laws in several. The original laws should be consulted to ascertain the exact requirements in each state.

In the anthracite mines of Pennsylvania, a miner cannot have more than 25 pounds of powder at any one place and time unless more is needed for the day's work. Gunpowder must be kept in a metallic or wooden box securely locked.

In the bituminous coal mines of Pennsylvania, the miners can take no more powder into the mine than is required for use in one shift unless this amount is less than 5 pounds. All powder must be carried into the mines in metallic canisters.

In West Virginia, the miner cannot take more powder or other explosive into the mine than he may reasonably expect to use in 1 day of 12 hours.

In Illinois, no blasting powder or other explosives shall be stored in any coal mine, and no workman shall have at any time more than one 25-pound keg of black powder in the mine, nor more than 3 pounds of high explosives. In the mine, all powder and other explosives must be kept in wooden or metallic boxes securely locked and at least 10 feet from the track, and no two powder boxes may be kept within 50 feet of each other, nor shall black powder and high explosives be kept in the same box. When about to open a box or keg containing powder or other explosives, and while handling the same, all lamps must be kept at least 5 feet distant and in such position that the air-current cannot convey sparks to it.

In Montana, not more than 1,000 pounds of blasting powder or other explosives shall be stored in the mine where its accidental explosion would cut off the escape of the miners working in the mine.

CHLORATE MIXTURES

22. Chlorate mixtures are not important in mining, since the use of potassium chlorate for the manufacture of explosives has been greatly restricted, owing generally to two causes: (1) This salt is a very unstable compound liable to undergo spontaneous ignition at any time; this tendency is increased by the presence of acid materials. (2) Chlorate mixtures are always sensitive to friction or percussion, and this increases with the lapse of time, and especially if the mixture be exposed to alternate moist and dry air. There are no important representatives of this class among mining explosives, except it may be rackarock, which will be treated under Sprengel explosives.

HIGH EXPLOSIVES

23. High explosives are of the detonating type and include the nitric derivative and nitro-substitution compounds, Sprengel explosives, fulminates, etc.

NITROGLYCERINE

24. Nitroglycerine is perhaps the most important of the high explosives and is a good representative of the single compound explosives. It is formed by the action of strong nitric and sulphuric acids on glycerine, which is a heavy oily liquid resembling syrup that although harmless by itself is very explosive when treated with certain nitrogen compounds.

In the manufacture of nitroglycerine, 3 parts of strong nitric acid are mixed with 5 parts of concentrated sulphuric acid. When this mixture has cooled, 1 to 1.15 parts of glycerine are added gradually, and the mixture constantly stirred, usually by means of compressed air. Great care is taken to prevent heating. The mixture is then poured into five or six times its bulk of very cold water, the nitroglycerine sinking to the bottom as a heavy oily liquid, which is clear and transparent when made from absolutely pure ingredients, but as ordinarily made it has a yellowish tint.

25. Properties of Nitroglycerine.—At ordinary temperatures, nitroglycerine, which is an oily liquid, has a specific gravity of 1.6. It does not mix well with warm water and seems to be unaffected by cold water. It is soluble in alcohols, benzene, carbon disulphide, ether, chloroform, and acetic acid. It has a sweet, pungent taste, is an active poison, and produces, in those unaccustomed to handling it, nausea, faintness, and severe headaches. Persons of a nervous temperament are more easily affected than others, but miners, who as a rule are nervous, become accustomed to handling it without any noticeable effect when placed in explosive compounds. Freshly made nitroglycerine freezes at 55° F., while purified nitroglycerine freezes to a white crystalline mass at 36° F. In the liquid state, when confined, a slight concussion may explode it, and it is therefore very dangerous to handle. When frozen, it is less sensitive to concussion than when liquid. Its firing point is 356° F., but it decomposes at a somewhat lower heat. After nitroglycerine freezes, it is dangerous to handle, and the process of thawing is always attended with difficulty; the force developed when exploded is also less after freezing. Nitroglycerine will burn, but a spark will not explode it, a concussion or detonation being needed to produce an explosion.

Nitroglycerine is little used in a free state, except for shooting oil wells, which have become clogged or do not flow. It is, however, one of the chief ingredients of the high explosives known as nitroglycerine compounds. Owing to its great liability to explode, it was useless as a mining explosive until Nobel invented *dynamite*.

DYNAMITE

26. Dynamite is an explosive in which the nitroglycerine, which is the active agent, is absorbed by some material called the *dope*. If the dope is merely an absorbent for the nitroglycerine and does not add anything to the explosive character of the mixture, it is said to be inactive. If, however, the dope is of such a composition that when the explosion takes place the dope is decomposed and increases the force of the explosion, the dope is said to be active. The term dynamite is ordinarily applied to nitroglycerine explosives in which the dope is inactive and special names are given to those in which the dope is active. Such mixtures have an advantage over nitroglycerine as they are not so sensitive and can therefore be much more readily and safely handled; they can also be made in various degrees of strength.

27. Dynamite With an Inactive Base.—Originally, dynamite was made by absorbing the nitroglycerine in an inert or inexplosive substance, such as *infusorial earth*, which consists of the silicious remains of certain microscopic plants called diatoms. This earth is very porous and when carefully prepared will absorb about 75 per cent. of nitroglycerine. Other inert substances, such as magnesium carbonate, sawdust, charcoal, etc., may be used as a dope but they do not hold the nitroglycerine as effectually.

Very little dynamite is made in America with a base of infusorial earth, as cheaper dopes, such as wood pulp, are available and it is claimed that they give an equal degree of safety. A silicious dope, such as diatomaceous earth, is inert and acts merely as an absorbent and leaves a residue when the dynamite is exploded. The wood pulp is usually mixed with sodium nitrate, which furnishes oxygen for burning the pulp when the dynamite is exploded. Sulphur, flour, and rosin are also sometimes added to the dope. An alkali, such as magnesium carbonate or zinc oxide, is also sometimes added to the dope to neutralize any acid that may be present.

28. Dynamite With an Active Base.—The force of an explosion of dynamite can be regulated by varying the amount of nitroglycerine it contains; but as dynamite containing less than 30 per cent. of nitroglycerine and having an inactive base cannot be exploded, it is impossible with such dynamite to regulate the force of the explosions below that limit. For this reason, ordinary dynamite is not satisfactory for blasting coal, rock for building purposes, etc., and in fact in all cases where shattering is a bad feature. If, however, some combustible or another explosive substance is used as an absorbent instead of an inert substance, the proportion of nitroglycerine can be made much lower and the force of the explosive thereby reduced. In other cases, by retaining the same percentage of nitroglycerine and using an active base, the force of the explosion is increased beyond that which the nitroglycerine alone will produce. There are a great many kinds of dynamite of this description, each with its special name, but comparatively few kinds are used in America.

29. The strength of ordinary dynamite depends on the amount of nitroglycerine it contains, thus 75-, 70-, 60-, 50-, 40-per-cent., etc. dynamite. Dynamite containing as low as 17 per cent. of nitroglycerine is used in salt mines, and in some quarries, for blasting glass sand, etc. Much of the dynamite now sold contains other explosive ingredients than nitroglycerine. This dynamite is classed as an ordinary dynamite and known as 40-, 50-, 60-per-cent., etc. dynamite, but in this case the name means that the particular dynamite has the same explosive force as pure 40-, 50-, 60-per-cent. nitroglycerine dynamite and not that the dynamite contains necessarily 40-, 50-, 60-per-cent., etc. nitroglycerine.

30. Carbo-dynamite is an explosive of this class and consists of 90 parts of nitroglycerine absorbed in 10 parts of charcoal, with the addition of 1½ per cent. of sodium carbonate which is added to render the explosive safer in handling.

31. Dynamites of a slightly different character are made by the addition of nitrates or chlorates, so as to render the combustible absorbent explosive of itself, thus practically combining two explosives. The effect is practically the producing of a less concentrated explosive of practically equal strength with that of the ordinary dynamites.

A few of the many explosives of this class are given in Table I.

The properties and action of these special explosives are, in general, the same as dynamite, the chief difference being

TABLE I

Name of Powder	Ingredients															
	Nitroglycerine Per Cent.	Potassium Nitrate Per Cent.	Sodium Nitrate Per Cent.	Sodium Carbonate Per Cent.	Magnesium Carbonate Per Cent.	Potassium Chlorate Per Cent.	Wood Meal Per Cent.	Wood Fiber Per Cent.	Wood Pulp Per Cent.	Pitch. Per Cent.	Rosin. Per Cent.	Sulphur. Per Cent.	Sugar Per Cent.	Charcoal Per Cent.	Cannel Coal Per Cent.	Infusorial Earth Per Cent.
Atlas A	75.0		2.0		2			21								
Atlas B	50.0		34.0		2			14								
American safety	68.8		18.4						12.8							
Carbonite*	25.0		34.0	.5			40.5									
Dualin	50.0	20					30.0									
Giant No. 1	75.0			.5												24.5
Giant No. 2	40.0		40.0								6	6				8.0
Hercules No. 2	40.0	31			10	3.34							15.66			
Judson	5.0		64.0									16			15	
Rendrock	40.0	40							13.0	7						
Stonite	68.0	8					4.0									20.0
Vulcan	30.0		52.5									7		10.5		
Vigorite	30.0	7			5	49.00			9.0							

*This is the original type, but there are numerous variations from these proportions.

in the quickness of action and the amount of flame produced. As a general thing, they are also stored, handled, and charged the same as ordinary dynamite.

32. Carbonite is one of the safety powders permitted in the mines of Great Britain; it differs from most high explosives in having a slow action more nearly resembling black powder, although it is from 2 to 2½ times as powerful. It is supplied in cartridges, freezes like dynamite, and when frozen is to be thawed in a similar manner. It requires a very powerful detonator for its explosion.

33. Ardeer powder is another so-called safety powder, in which the high temperature from the nitroglycerine is lowered by the addition of magnesium sulphate which contains considerable water of crystallization; this results in a decrease of flame in its explosion, which renders it a valuable explosive in coal mines. It is said to be as cheap as, and 50 per cent. more powerful than, black powder, and requires a detonator of only medium strength.

34. Table II gives the brands of blasting explosives having equal strength; the percentage of nitroglycerine is also given for each brand of Atlas powder.

35. Properties of Dynamite.—Good dynamite is rather plastic and not greasy. The density, or specific gravity, depends on the dope and is usually about 1.15. Dynamite has the physical properties of nitroglycerine as far as explosive power is concerned and is equally poisonous to those unaccustomed to handling it. See Art. **25.** Its firing point is 356° F., at which temperature it will either burn or explode; if free from gas or pressure it will burn, but if jarred it may explode. The sensitiveness of dynamite to blows or shocks increases very rapidly with a rise of temperature. Dynamite freezes at about 43° F.; and when solidly frozen it is difficult or impossible to explode it, or if it does explode the detonation is at best only partial. It is dangerous to cut, break, or ram a frozen dynamite cartridge, as the frozen nitroglycerine crystals may explode. No attempt should be

TABLE II

Atlas		Other Brands of Equivalent Strength						
Brand	Nitro-glycerine Per Cent.	Repauno Gelatine	Hercules Powder	Hercules Gelatine	Giant Powder	Giant Gelatine	Hecla Powder	Ætna Powder
A	75	A	No. 1 XX	No. 1 XX	No. 1+	No. 1+	No. 1 XX	
B+	60	B+	No. 1	No. 1	No. 1 A	No. 1	No. 1 XS	No. 1
B	50	B	No. 2 SS	No. 2 SS	New No. 1	No. 2	No. 1 X	No. 2 XX
C+	45	C+	No. 2 S	No. 2 S	No. 2 Extra			No. 2 X
C	40	C	No. 2	No. 2	No. 2	No. 3 C	No. 1	No. 2
D+	33		No. 2 C		No. 2 C		No. 2 X	No. 2 C
D	30		No. 3		No. 3		No. 2	No. 3 X
E+	27		No. 3 B		XXX		No. 3 X	No. 3
E	20		No. 4 B		XXXX		No. 3	No. 4

made to explode dynamite that has been frozen until it has been thoroughly thawed and is soft and plastic; many accidents occur through failure to observe this precaution. If incomplete detonation occurs, unexploded powder is often found in the holes or in the material blown down by the shot.

In cold weather, the cartridges should not be taken to the place where they are to be used until all the holes are ready to be loaded, and all cartridges should be soft and warm when charged into the holes. Experiments have proved conclusively that dynamite that has been chilled, but not frozen, loses a large part of its efficiency. Many instances are on record in which some of the holes of a blast were loaded with warm, and others with frozen, or partially frozen, dynamite; the dynamite that had been warmed exploded and that which was frozen did not, and miners have subsequently been killed or injured by drilling into these misshots.

If in examining the scene of the blast after a shot, the miners find unexploded dynamite that is warm, they immediately conclude that the dynamite was defective, and for this reason did not explode, while, in reality, it may have been frozen, and been thawed by the heat produced by the explosion of part of the charge.

36. Thawing Dynamite.—In thawing dynamite, it is necessary to use considerable caution to keep the temperature from rising very high, as each degree rise is that much nearer the danger limit where extreme sensitiveness to shock prevails. The method of thawing dynamite by placing it in a tight box surrounded by manure is a good one if the manure is fresh so that it is giving off heat, but it is useless to place the dynamite in an old manure heap from which no heat is being given off.

Dynamite cartridges should not come in direct contact with the manure, which, being moist, draws more or less nitroglycerine from the absorbent. Dynamite should never be thawed before an open fire, on a shovel, in a tin can, or in an oven, for, while dynamite will very frequently burn in the open and when unconfined, it very often explodes. The common practice of thawing dynamite cartridges by passing them through an oven or over a lighted candle is very dangerous.

37. Special thawing kettles, as shown in Figs. 1 and 2, are used with advantage to thaw frozen dynamite. The device shown in Fig. 1 consists of a metal can having tubes that pass through it. The tubes are surrounded by water, and the whole is so arranged that a miner's lamp or candle can be placed underneath the can to keep the water warm. When in use, the holes *a* are filled with sticks of dynamite, the space surrounding them is filled with water, and the cover *b* is slipped over in such a manner as to keep the sticks from falling out of the tubes. Then a lamp or a candle is placed under the pan and the powder will soon be ready for use. These thawers are especially useful as they can be carried from place to place in the mine, and the warm water in the portion surrounding the tubes will keep the powder in good condition for some time, even without the introduction of a lamp under the pan.

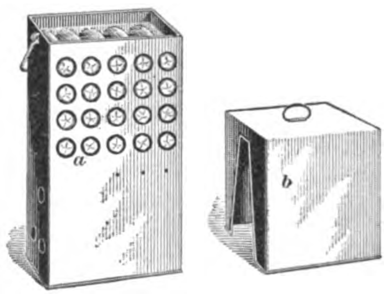


FIG. 1

Fig. 2 shows a double thawing kettle very commonly used. It consists of an outer kettle *b* standing on legs and an inner kettle *a*, which is held up by a bead around the top and in which the dynamite cartridges are placed, as shown. This inside kettle thus consists of an annular ring that is entirely surrounded by water and will hold forty-two cartridges, each of which is $1\frac{1}{4}$ by 8 inches in size. To thaw dynamite with

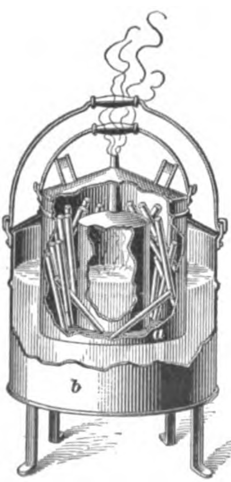


FIG. 2

this device, the outer kettle *b* is filled with water, which is heated by a fire placed underneath or by any other desired method. The kettle is then taken from the fire and set on sawdust or some other non-conductor of heat and the inside kettle *a* placed in position, sticks of dynamite put in, and the entire kettle then covered with a cloth to keep in the heat. The water in the kettle should never be reheated, as it may contain drops of nitroglycerine, which may ooze from the cartridges and leak through the bottom of the inner kettle in case there are any holes in it. When it is necessary to refill the kettle, add warm water from another vessel.

38. When larger quantities of high explosives are required on temporary work, an excellent device is to place the cartridges in a large dry milk can and the can in a cask or barrel containing water, which may be heated by a jet of steam. If steam is not available, the cask can be filled with warm water as often as necessary. The cask should be covered with some insulating material to retain the heat.

If the water in the cask is to be heated by a jet of steam, the nozzle throwing this jet should be placed as far as possible from the side of the can, or other metal case containing the explosive, since too great heat might be generated.

39. Storing Dynamite.—In regard to the storage of dynamite, there are several points of importance to be considered. While nitroglycerine is a liquid with a high boiling point, it evaporates sensibly at a temperature a little over 100° F., and on this account dynamite should never be heated to a point much above this limit. Dynamite cartridges should always be laid on the side and not stood on end, for in the latter position the nitroglycerine will ooze from the dope and collect in the bottom of the cartridge.

As a rule, dynamite should be stored in a dry place having a fairly even temperature. Stoves or live-steam pipes should never be allowed in a building in which the dynamite is stored, but if this building requires artificial heat, it should be imparted by means of hot-water or exhaust-steam pipes, and the temperature should not rise above 100° F. When dynamite is being used on a large scale during the winter, it is well to provide a special thawing room, in which 1 or 2 days' supply of the material can be kept ready for use. This may be a small house situated some distance from the engine house, but connected with the engine exhaust or exhaust drip pipe in such a way that the heat may be imparted to the room in which the dynamite is stored.

Double walls, floors, and ceiling with a sawdust filling answer every purpose, but the building must be made absolutely tight. A crack under a door or window will counteract the best heating system that can be made.

If steam is available, a very cheap and efficient system of heating a small building is as follows: On the outside of the building a sheet-iron drum is set up and connected with another inside. Two pipes pass through the wall connecting the drums near the top and bottom. The outside drum is set a little lower than the other to provide for the overflow of the water. The holes through the walls are packed around the pipes with waste or tow. Water in the outside drum is heated by a small steam pipe and circulates through the drums. The room is kept warm by the radiation from the inside drum. If the building is tight and properly insulated, the amount of steam necessary is very small. To prevent the vapor from making the room damp, the drums are closed on top with wooden lids covered on the under side with cloth soaked in paraffin. The sheet-iron drum used for the transportation of glycerine or coal oil is well suited for this work.

When dynamite is being used in winter on a large scale, as at a mine, it would pay to build a small thawing room of this kind, say 12 feet by 16 feet. The powder needed for the day's consumption could be carried in and left for 12 hours or more, the boxes being simply opened or the powder taken out and put on shelves, depending on the time available. A temperature of 75° or 80° maintained during the night would suffice to thaw the powder. A thermometer should always be consulted to regulate the temperature of the room, which should not exceed 85°.

This particular arrangement for a thawing room is convenient, but it may be varied to suit the case. The essential feature is a tight, heat-insulated room kept at a moderate and regulated temperature.

If a stone or brick vault is made below the surface and tightly roofed over and banked with earth, dynamite may be kept all winter in it without freezing. Storing dynamite in large quantities in a mine is both bad practice and dangerous.

40. Size of Dynamite Cartridges.—Dynamite cartridges are made 8 inches long and $\frac{7}{8}$ inch to 2 inches in diameter. The sizes most generally used are $\frac{7}{8}$ inch, 1 inch, $1\frac{1}{8}$ inches, $1\frac{1}{4}$ inches, $1\frac{3}{4}$ inches, and 2 inches in diameter. These are packed with sawdust in wooden boxes that contain 25 or 50 pounds of dynamite; hence, a car load of 10 tons will contain 400 cases of the larger and 800 cases of the smaller size.

41. Firing Dynamite.—Dynamite cannot be fired by means of simple ignition, as is the case with black powders; a powerful detonating cap is necessary to develop its full force. There is a widespread but erroneous idea that the action of dynamite is mainly downwards. This cannot be so as the force of dynamite, as of all explosives, is due to the volume and temperature of the gases formed, and a gas must necessarily act equally in all directions.

GUNCOTTON

42. Chemically, **guncotton**, or **nitrocotton**, resembles nitroglycerine. It is prepared from ordinary cotton by treatment with strong nitric and sulphuric acids, which converts the cellulose of the cotton into trinitro cellulose and other highly nitrated compounds. Fibrous guncotton differs but little in appearance from ordinary cotton, but it is harsher to the touch and less flexible. It is insoluble in hot or cold water but is readily soluble in many other liquids. To be exploded, dry guncotton must be compressed and detonated, otherwise it will simply burn. Wet guncotton will not explode unless detonated by means of a fulminate-of-mercury detonator in a rubber sack in contact with a small charge of the dry cotton, but under these conditions it explodes more violently than when dry.

By itself, guncotton is not much used in mining, but it forms the basis of a number of powerful powders, among which are *tonite*, consisting of guncotton 52.5 per cent. and barium nitrate 47.5 per cent.; and *potentite*, consisting of guncotton 66.2 per cent. and potassium nitrate 33.8 per cent.

BLASTING GELATINE

43. Blasting gelatine is an exceedingly powerful explosive made by dissolving guncotton in nitroglycerine. It is a thick jelly-like mass that resists the action of water better than dynamite, the nitroglycerine having a tendency to exude from the dynamite under water. Blasting gelatine was prepared by both Nobel and Abel about the same time (1875), they having noticed that in the explosion of nitroglycerine an excess of oxygen remained, while in the explosion of guncotton an excess of carbon remained, and thought that by the mixture of these explosives a more perfect combustion would be obtained.

Blasting gelatine is a yellowish brown elastic substance having a specific gravity of 1.6. It does not absorb water and is only slightly affected at the surface when immersed in water. Unconfined, it burns with a hissing sound, but does not explode. If confined, it explodes at 399° F. It freezes at a temperature between 35° and 40° F. and is far more sensitive when frozen than unfrozen, so that it is particularly adapted for use in warm climates and in warm weather.

44. Gelatine dynamites are formed by absorbing blasting gelatine in an active base, in the same manner as other dynamites are formed by absorbing nitroglycerine in a dope.

A number of brands of gelatine dynamite are manufactured and very largely used in the United States. The advantages claimed for explosives of this class over ordinary dynamite are the following: The gases produced by exploding gelatine dynamite are less injurious than those made by the explosion of ordinary dynamite. It is therefore possible for the miners to return to work sooner after a shot, and they are also in much better physical condition for the balance of the shift.

Gelatine dynamite is heavier, bulk for bulk, than ordinary dynamite and is therefore more easily loaded in water. This greater density also allows of a shorter charge and thus brings the center of the explosion lower than in the case of ordinary dynamite, resulting in an actual saving in the length of drill holes necessary, and rendering it particularly adaptable for very hard rock. It is affected less by water and is especially suited for all submarine work or for use in very wet mines. It is more plastic, sticks readily in upward driven holes, and cannot be rattled out by other shots.

45. The best-known explosives belonging to this class are, Repauno gelatine, Hercules gelatine, Atlas gelatine, giant gelatine, Ætna gelatine, and forcite. The exact composition of these gelatine explosives is not made known by the manufacturers and is constantly varied to meet changing demands and conditions. All are less sensitive than ordinary dynamite and should be exploded by caps of not less than XXXXX strength or by double-strength electric exploders.

46. The following are two examples of foreign gelatine dynamites: **Gelignite** is a gelatine powder much used in England and Japan. It is practically unaffected by water, and is much safer than dynamite to handle. It freezes at about 45° F. but thaws somewhat more readily than dynamite. It is less shattering than dynamite. Its composition is:

		Per Cent.
Blasting gelatine, 65 per cent.	Nitroglycerine	96.15
	Guncotton	3.85
Absorbent, 35 per cent.	Sodium nitrate	75
	Wood pulp	24
	Sodium carbonate	1

Dynamite de Franzel contains seventy-five parts of nitroglycerine, twenty-five parts of guncotton, and two parts of charcoal.

PICRATES

47. **The picrates** belong to the nitro-substitution compounds, being formed by the action of nitric acid on phenol (carbolic acid) or certain organic substances such as silk, gums, etc. The explosive *lyddite*, used for charging bombs or shells, is an example of this class. Potassium picrate is a most sensitive and explosive compound, and when mixed with potassium chlorate its explosive strength equals that of nitroglycerine, but it is more sensitive and unreliable. The picrates are too sensitive to make a safe explosive for mining use.

SPRENGEL EXPLOSIVES

48. This class of explosives depends on the mixture, immediately before using, of two substances not of themselves explosives, but forming an explosive mixture when combined. The explosives of this class have proved of considerable importance in mining from the fact of their producing a minimum amount of flame when exploded. They represent very largely what have been called the flameless explosives. This character is due to the fact that the products of their explosion are almost wholly incombustible. The Sprengel explosives require strong detonators, and are considered safe and valuable explosives. The most important of these is rackarock, which has the following composition: potassium chlorate, 79 per cent., mono-nitrobenzole, 21 per cent.

The cartridge of potassium chlorate is immersed in the nitrobenzole a few seconds before using.

49. The composition of some of the Sprengel explosives whose use is permitted in Great Britain are given in Table III.

TABLE III

Name of Explosive	Ammonium Nitrate Per Cent.	Barium Nitrate Per Cent.	Dinitro Napthaline Per Cent.	Dinitro Benzol Per Cent.	Dinitro Benzol and Chlorinated Napthaline Per Cent.	Chloro Napthaline Per Cent.	Wood Meal Per Cent.	Wood Meal and Starch Per Cent.	Rosin Per Cent.	Moisture Per Cent.	Detonator Number
Ammonite	88		12								6½
Amvis	90				4.5		5			.5	Special
Bellite No. 3	94			5.25						.75	7
Electronite	73	19						7.5		.5	7
Roburite	87			11		1.5				.5	Special
Westfalit No. 1	95								4.5	.5	8

REQUIREMENTS OF A MINING EXPLOSIVE

50. Many explosives that have great power and are admirably suited for use on the surface are not suitable for use in the mines. An explosive for use in the mines should not be too sensitive to variations of temperature and to shock and should be reasonably safe in storing and handling; should possess the required strength; should produce a minimum amount of flame when exploded; the products of its combustion should not be poisonous or corrosive in their action; the ignition of the explosive should be positive and reliable. In some cases, it is desired to break the material as thoroughly as possible; but in others, and generally in coal mining, the explosive should break with as little shattering as possible. It is not possible to realize all of these requirements in a single explosive; some explosives present a greater degree of safety in handling and storing but less strength; some powerful explosives produce injurious effects by the action of their gaseous products; some otherwise good explosives are too sensitive to the dampness of the mine, while others are too sensitive to shock due to careless handling. In American practice, comparatively few types of explosives are used, the principal ones being black powder and nitroglycerine explosives, together with the flameless explosives of the Sprengel class.

COMPARISON OF EXPLOSIVES IN REGARD TO SAFETY

51. As in all other branches of mining, the question of the safety of explosives must be considered first. It will be necessary therefore to look carefully into the safety in handling and also into the various effects produced by firing the different explosives under varying conditions.

52. Safety in Handling.—Under this head, may be included, storage, conveyance to and about the mine, and charging. There is no doubt that explosives of the Sprengel class, requiring a detonation of 15 or 18 grains of detonating substance, are the safest, since a fairly large amount of heat is required to ignite them. This not only avoids risk of sudden and unexpected ignition, but secures more rapid and complete decomposition of the explosive. With gunpowder, the risk of sudden accidental ignition by sparks, before the charge is ready for firing, will always be a source of danger, although the ignition point of gunpowder is much higher than that of the nitroglycerine compounds. The liability of many explosives to exudation and freezing is a drawback as the liability to accidents during the process of thawing is increased.

53. Safety When Firing.—It is during firing, however, that the greatest danger arises. There are three conditions with which a safety explosive should comply: First, that the products of combustion shall be non-combustible; second, that the heat generated shall be as little as possible; third, that there shall be a rapid and complete decomposition of the whole of the explosive. In regard to the first and second conditions, it is claimed that, in certain explosives, such as ammonite, electronite, and roburite, these conditions have been attained by using such ingredients, and so proportioning them that they will insure, on detonation, a degree of heat insufficient to ignite inflammable gas or coal dust, and that the products of combustion are non-inflammable, being chiefly composed of carbon dioxide, water vapor, and nitrogen. It cannot be denied, however, that all so-called safety explosives have at one time or another given off flame, which would have been sufficient in case of an accumulation of gas or coal dust, to have produced an explosion. This may not be due to faulty explosives, but entirely to the conditions prevailing in the mine at the time. All the requirements of a safety explosive may have been fulfilled and the usual precautions taken in firing, but in spite of these a flame may be produced. It is well known that carbon monoxide is formed in consequence of an insufficient supply of oxygen or an excess of carbon in the explosive.

Carbon monoxide is inflammable, and when mixed with air forms an explosive mixture. It is more readily ignited, and requires less heat to explode than firedamp, so that, whereas, the presence of carbon dioxide is likely to reduce the risk of the ignition of surrounding gases, the presence of carbon monoxide increases considerably the danger from this cause. Thus while under favorable conditions no inflammable products may be produced during the firing of certain explosives, the same explosives may under unfavorable circumstances cause carbon monoxide to be formed, and that becoming ignited, in its turn, may ignite inflammable mixtures of firedamp, or coal dust, and air.

In regard to the third condition, it is often found that owing either to an unsuitable detonator, breaks in the coal (which sometimes contain blowers of gas), or inefficient tamping of the drill hole, the rapid ignition of the explosive is not brought about. The rate at which an explosive burns when it is not detonated depends on the pressure in the hole. If the coal or rock breaks down before the whole of the explosive is decomposed, there is danger of ignition of gas by the fizzling particles, which throw out sparks into the surrounding atmosphere. In order to avoid risks arising from insufficient strength of detonator, some explosives, such as carbonite and westfalit, are so constituted as to require detonation to commence, but combustion to complete the decomposition. A luminous flame is not always the most dangerous, because such a flame may be produced at a low temperature; while in other cases at exceedingly high temperatures, the flame may be non-luminous.

Although certain explosives are classed in the safety list, this does not guarantee absolute freedom from danger in fiery mines. Miners must, therefore, bear in mind that even the best explosives are not absolutely safe, there being no explosive yet made that has not under some conditions proved faulty.

In firing a blast, it often happens that some shots going first, cut off the fuse leading to a charge before the fire passes through, and a misshot results. This is the most dangerous of all misshots, since the cap remains in the dynamite, and is almost certain to explode when drilled into accidentally, or when the miners attempt to investigate by probing the hole with their scrapers, and so explode the cap, which is really the most sensitive and dangerous thing used.

54. Safety After Firing.—By this is meant freedom from smoke or noxious fumes. Complaints are regularly made by those engaged in shot firing of the bad effects of the products of combustion. Carbon dioxide, carbon monoxide, and water vapor are often the chief constituents of the gases evolved; and although carbon monoxide is the most dangerous gas, carbon dioxide is depressing and unhealthful if breathed for any length of time. To avoid the production or accumulation of these gases, good ventilation is absolutely necessary, and is the only preventative of serious results. If coal dust is present, however, something more than ventilation is required. It will be necessary to prevent the accumulation of the dust as much as possible, and to adopt suitable means of watering. By these methods, the possibility of the formation of carbon monoxide in consequence of lack of oxygen or from excess of carbon, will be diminished.

55. Dangers From the Excessive Use of Powder. In some coal-mining localities, where the quantity of coal mined is of more importance than its condition, there is a tendency for the men to use excessive charges of powder. This practice has led to a number of disastrous explosions, and the moderate use of powder cannot be too strongly urged. When too much powder has been used, the force of the explosion of the excess is expended in the chamber, and, in addition, the inflammable carbon monoxide produced mixes with the air and carries the flame to other parts of the workings, where accumulations of gas may be fired.

MEANS OF FIRING EXPLOSIVES

56. Blasts are fired by means of fuses, squibs, or detonators, depending on the nature of the explosive and on other circumstances. Black powder, which explodes on simple ignition, is almost always fired by fuses or squibs. High explosives, requiring detonation, may be fired by means of a fuse to which a detonating cap is attached.

FUSES

57. A **fuse** is a slow match used to convey fire to the charge of explosive in a hole. Fuses are made in a number of ways, depending on the use for which they are intended.

58. Waterproof Fuses.—For blasting purposes, it is often necessary to use a fuse that will not be injured by water. These are made by impregnating a small jute thread with fine gunpowder. This forms a slow match that is first covered with a layer of jute yarn, after which it is wound with tape and then coated with tar and covered with fullers' earth or talc powder to prevent its sticking. Such a fuse is called a *single-tape fuse*, and it is put up in loose rolls containing 25 feet each. Fuses vary widely in their rates of burning, and while a fuse should not burn more quickly than 2 feet per minute the rate varies from 18 inches to 4 feet per minute. Hence, before using a fuse its rate of burning should be determined by thoroughly testing it.

59. Double-tape fuses are single-tape fuses wound with another layer of tape, the latter also being tarred and powdered. Double-tape fuse is surer than single-tape, at least where there is moisture present. It is put up in coils, of 25 feet each, that are packed in cases containing 6,000 feet. Triple-tape fuse is also manufactured for use in firing very wet holes, but it has been gradually displaced for this purpose by electric fuses fired by electric batteries, which are very effective.

60. Cotton, or hemp, fuse, not tape wound, is manufactured but is only suitable for use in absolutely dry places and in hot climates.

61. Special Safety Fuses.—In cold countries, fuse covered with tar is apt to crack, in which case it may miss fire or become wet; to obviate this difficulty specially coated fuses are manufactured. In hot countries, the ordinary tar-covered fuse becomes sticky and is not suitable for use, therefore specially coated fuses are manufactured for the tropics. When it is desired to fire shots under water, a gutta-percha covered fuse has been manufactured. It is not, however, as sure in deep water as an electric fuse, since the pressure may permit water to work into the cartridge and saturate the fuse, rendering it worthless.

62. Quick-burning fuses are made by making the core of the fuse cotton wick saturated with chemicals that make it very quick burning. One mixture used for this purpose is a paste of equal parts of ferrocyanide of lead and potassium chlorate mixed with alcohol. Such a fuse burns at the rate of 500 feet per minute.

A practically instantaneous fuse, known as a *detonating* fuse, has a core composed of a cotton thread saturated with fulminate of mercury. This fuse is said to burn at the rate of 16,000 feet per second and is set off with a detonating cap.

63. Care of Fuse.—Fuse should be kept dry, preferably in tin cans, and out of contact with oil. It should be stored where it will not be subjected to sudden changes in temperature.

SQUIBS

64. A **squib** consists of a small paper tube, or straw, that is filled with a quick powder and has a slow match attached to one end. The burning of this slow match gives the miner time to get away after lighting it and before the flame reaches the quick powder. When this quick powder is fired, it shoots like a rocket through the hole that has been left in the stemming or tamping back into the blasting powder. Squibs are used almost universally by coal miners instead of fuse. They are used as follows: While charging a hole, a pointed copper wire, called a *needle*, which is of a length greater than the depth of the hole is introduced into the cartridge. Iron needles are frequently used, though this is contrary to law in many states. The stemming or tamping is rammed about this needle and when the hole has been sufficiently filled the needle is drawn out, thus leaving a hole through the tamping to the powder. The squib is introduced into this hole and when it is fired carries the flame back to the powder charge. There is an element of danger connected with the use of squibs in a gaseous mine, as flame from the explosion of the charge may shoot out through the hole left for the squib and ignite the gas. Holes tamped with clay and fired by fuses are preferable in a gaseous mine.

65. Fig. 3 shows a safety squib composed of two parts, a powder tube *a* and a slow match *b* for firing the powder. The powder tube *a* slides inside of the match tube *b* so that

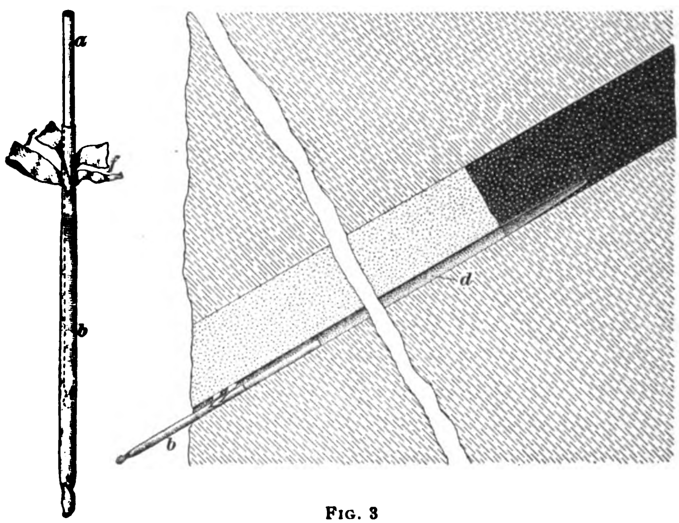


Fig. 3

the time of firing can be regulated; *d* is a needle hole. The rough edges *f* of the squib engage with the sides of the needle hole, preventing the squib from falling into the hole or out of it, thus making this squib particularly adapted for holes having an upward or downward inclination.

DETONATION

66. Fulminates.—When it was ascertained that a blow or shock would explode nitroglycerine, that is, detonate it, attention was turned to some artificial means of producing the shock. Fulminates of mercury, silver, gold, platinum, zinc, and copper are violent explosives and extremely sensitive to heat and shock. The material generally used for detonation is fulminate of mercury seventy-five parts, potassium chlorate twenty-five parts, and gum to give coherence to the mass and reduce the danger in handling. Fulminate of mercury explodes when heated slowly to 305° F., but is less sensitive when wet. Sometimes silver fulminate replaces the mercury fulminate, but it is still more dangerous.

67. Detonators are metal caps containing various weights of fulminate. Some explosives require more violent detonation than others; hence, detonators are manufactured of different strengths to meet different requirements. A common method of designating detonators is, triple strength, containing 5 grains of fulminate of mercury; quadruple strength, containing 7 grains of fulminate of mercury; quintuple strength, containing 9 grains of fulminate of mercury. Single- and double-strength detonators are not used in the United States. Another common method of designating the above strengths is by the number of X's, as XXX, XXXX, and XXXXX, etc. Still another method is by numbers as follows:

Detonator No. 1	contains 4.5	grains of fulminate of mercury
Detonator No. 2	contains 6.0	grains of fulminate of mercury
Detonator No. 3	contains 8.0	grains of fulminate of mercury
Detonator No. 4	contains 10.0	grains of fulminate of mercury
Detonator No. 5	contains 12.0	grains of fulminate of mercury
Detonator No. 6	contains 15.0	grains of fulminate of mercury
Detonator No. 6½	contains 19.0	grains of fulminate of mercury
Detonator No. 7	contains 23.0	grains of fulminate of mercury
Detonator No. 8	contains 30.9	grains of fulminate of mercury

Detonators or caps are very powerful and if exploded in the hand will cripple that member, hence are not to be trifled with. They are put on the market in lots of one hundred, packed in metal boxes. There is no economy in purchasing poor caps, or those not strong enough to properly explode the charge, since the best results are always obtained by using strong detonators. Many advise the use of the strongest detonators procurable for all mine work. Fulminate caps are discharged by time fuse or by electricity.

68. Deterioration of Caps.—While the cap that is properly kept is the most reliable of all the blasting materials used underground, it is also the most susceptible of deterioration. It should be one of the first rules in the use of explosives to use the material as soon as possible after the original package is open and not to open another package until that is done. Caps sometimes explode without detonating the cartridge. An explanation often advanced for this is that the cap is too weak, but this does not explain the fact that a stick of powder that a XXXX cap fails to explode may often be readily detonated by a XXX cap, showing that in the first case failure to explode was probably due to deterioration of the cap. The following experiments were made at Leadville some years ago and from the results it would appear that it pays to keep the caps out of the mine until they are needed. Fresh XXX caps gave complete detonation; when kept underground 24 hours they gave incomplete detonation; when kept underground 48 hours they gave incomplete detonation, without red fumes; after 72 hours, one of the same caps exploded without detonation and finally when kept underground 144 hours the cap refused to explode. The experiments were made under bad conditions, but possibly not more so than occur in very many mines. They show that if a very damp atmosphere has the effect of so weakening the cap that it explodes without detonating the dynamite, then any damp atmosphere must cause the cap to deteriorate. Experience has shown that in warm climates with 35-per-cent. dynamite, XXXX caps give good results and with 40-per-cent. dynamite, XXX caps. In cold climates, 35-per-cent. dynamite will give better results when detonated by a XXXXX cap than when a weaker cap is used. Similarly, with a 40-per-cent. powder, XXXX caps should give better results than XXX, and XXXXX better than XXXX.

It is probable that temperature has something to do with detonation, and that misfires are often due to the chilling of the explosive after it is taken from the magazine. For example, in a warm climate when using 40-per-cent. powder and fresh caps, a misfire through non-detonation by the cap is rare, and the fumes are also less in volume and not so noxious as they are with a similar explosive in a colder climate, where it is not uncommon to find a chilled dynamite charge scattered by a cap without explosion.

69. Strength of Detonator to be Used.—Experiments should be made to ascertain the effect of different caps on charges by noticing the amount of rock broken and the fumes made by the explosive. The following is a record of such a series of experiments in which 40-per-cent. dynamite was used; the caps employed were XXX, XXXX, and XXXXX. Three drifts were selected, the ground being as nearly as possible of the same character, the entire rock being diabase. The different caps were used for 1 week in each of the drifts and the advances of the drifts carefully measured. The amount of dynamite used in each case was noted and the section of the drifts measured as accurately as possible. The number of cubic feet of rock broken by a pound of dynamite was taken as the measure of work done in each case; the results were as follows:

Drift	Caps Used		
	XXX	XXXX	XXXXX
	Cubic Feet of Rock Broken		
No. 1	19.4	23.5	22.8
No. 2	17.6	24.2	25.1
No. 3	18.7	22.6	23.7
Average	18.6	23.4	23.8

The advantage of the XXXX and XXXXX caps over the XXX was fully 25 per cent.; and while the XXXX and XXXXX gave pretty much the same results; such differences as were recorded may have been due to accidental causes.

Particularly since in drift No. 1, the XXXX caps gave slightly better results than the XXXXX. The results were apparently more certain with XXXXX caps than with XXXX caps. The slightly better work of the XXXXX caps was ascribed to the liability of the powder to chill at the time the experiments were conducted. In summer, the practice was to use XXXX caps, but in winter XXXXX caps gave better satisfaction; many prefer the stronger cap at all seasons.

It is well known that men cannot work as well in bad air as in good air, and this result was demonstrated for the men when using the stronger caps made much better headway than when using the weaker caps. The difference in cost was also marked. When using XXXX caps, the distance driven was 72 feet, at a cost of $5.75 per foot; when using XXXXX caps the distance driven was 72½ feet, at a cost of $5.72 per foot; and in the case of XXX caps the distance driven was 64 feet, at a cost of $6.32 per foot.

70. Electric detonators, sometimes called **electric fuses**, are copper caps containing fulminate of mercury and some other explosive, that is fired by means of electricity.

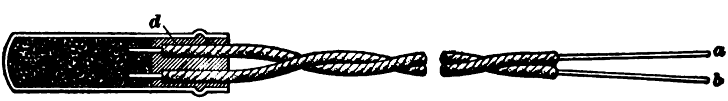


Fig. 4

Such a detonator is shown in section in Fig. 4. The wires *a*, *b* that carry the electric current to the explosive *c* are bare inside the cap and held in place by a cement *d* of sulphur to protect the explosive compound, and are connected by a short piece of platinum wire or *bridge e*. When the current of electricity passes through the platinum wire *e* the latter becomes heated, thus igniting the explosive.

There are two types of electric detonators termed high-tension, and low-tension. The former is being gradually replaced by the latter, because it is possible to test the low-tension detonator by means of a galvanometer, while the high-tension must be fired to test its quality, and then there is no surety that the next fuse will explode.

BLASTING

CHARGING DRILL HOLES

71. Gunpowder is put up by the miner in paper cartridges of less diameter than that of the drill hole, and these are placed in the bottom of the drill hole. If the hole is dry, these cartridges may be tamped hard enough to break the cartridge paper so that the powder will pack closely and fill all spaces, for the closer the powder is packed in the hole the greater will be the effect produced by the blast. In case the hole is in seamy rock, a ball of clay is first put in the hole and then a *clay bar* driven into it, to spread it out and fill all crevices. If these crevices are not filled, the gases due to the explosion escape through them and much of the force of the explosive is lost. The **clay bar** is a good hickory or oak stick with a slightly pointed iron shoe at one end, or is an iron bar pointed at one end with an eye at the other for removal from the hole. To make the hole round, after using the clay bar, an auger may be turned in the hole and the surplus clay removed. Should the hole be wet, the same method of claying is followed, but the cartridges are well coated with miners' soap and not tamped so hard as to break them. The use of metal bars in charging a hole should be discouraged and wooden bars used whenever possible.

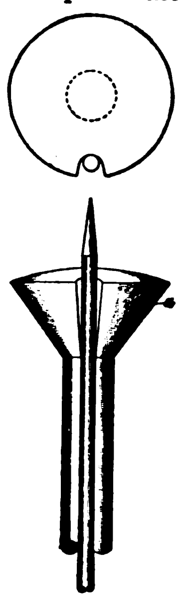


Fig. 5

72. The **needle**, which is about $\frac{1}{4}$ inch in diameter and pointed, is run into the cartridge, and about it the tamping is rammed by means of a **tamping bar**, which has a groove through the head to accommodate the needle, as shown in Fig. 5. This is usually of iron with a copper head *a* of large diameter; it is also made entirely of copper where cartridges are not used, since if iron comes in contact with rock or pyrites it is apt to spark and cause a premature blast if loose powder is present. The tamping is put in and tamped little by little, the first few inches being rammed hard and the remainder only packed sufficiently tight to keep open the needle hole when the needle is removed.

In anthracite mines, the **blasting barrel** is often used instead of the needle, since tamping fine enough to pack is not obtainable unless the miner pounds up slate and coal. The **blasting barrel** is a steel or wrought-iron tube of about $\frac{1}{4}$ inch inside diameter; one end is inserted in the cartridge and the squib is fired through it to the powder. The rammer fits over the blasting barrel in the same way as over the needle shown in Fig. 5. The blasting barrel is valuable where the tamping is damp or the hole slightly wet, but after each shot is fired it has to be recovered and if used again must be straightened.

In putting paper cartridges into holes, care should be taken not to break the paper until the bottom of the hole is reached. The tamping material is preferably clay, but it may be any fine loose dirt that will pack sufficiently to leave a hole after the needle is removed.

73. Amount of Charge.—There is no rule that will apply in every case as to the amount of powder necessary to use in blasting. The judgment of the miner must determine that from experience. If shooting is done off the solid, more powder will be required than when there is an undercut, or a good slip. It is useless to go into the very many phases that the miner will meet, and determine the amount of the charge to be used, but this can be said, point the hole right, and listen to the sound of the explosion. If the sound is sharp and cracking too much powder has been used; if the sound is a deep boom the proper quantity has been used. The depth of the hole is also to be considered, since a shallow hole will not require as much powder as a deep hole.

In bituminous workings varying from 4 to 6 feet in thickness with coal of medium hardness, it is common practice to drill a hole varying from 2 to $2\frac{1}{2}$ inches in diameter and to use from 2 to 6 pounds of powder, depending on the coal, thickness of the seam, etc. Three-inch holes are used in some cases, but do not give as good results.

The amount of black powder used in blasting coal is in many cases excessive. Experiments made in Illinois during the summer of 1905 and the testimony of witnesses on the same subject, showed that in an entry 10 feet wide and 7 feet high, and in rooms 30 feet wide and 7 feet high, less than 2 pounds of powder was usually required to bring down the coal in the best marketable condition. From three to four times this amount is, however, frequently used.

It is impossible to give any general rule that will apply for different mining regions.

74. Relation of Diameter of Hole to Length of Charge.—By experience, it has been proved that, as a rule, the length of the charge of explosive for single holes should not exceed from eight to twelve times the diameter of the hole; that is, a 1-inch hole should never have a charge of more than 12 inches of explosive placed in it. Where several holes are fired together, this rule is sometimes slightly deviated from. It is usually best to employ a length of charge between these two limits, as, for instance, about ten times the diameter of the hole.

After the proper relation between the diameter of hole and the length of charge has been determined by experiment for a certain diameter of hole under given conditions, it is safe to conclude that the same ratio of length of charge to diameter may be taken for other diameters. Thus, if it has been found that for a hole 2 inches in diameter the best results are obtained from a charge 24 inches long (2×12), it may be assumed that in a hole $2\frac{1}{2}$ inches in diameter the charge should be $2\frac{1}{2} \times 12 = 30$ inches long.

Table IV is given by A. W. and Z. W. Daw, for the weight, in pounds, of the charge for bore holes of different diameter and for different explosives, assuming the length of the charge to equal twelve times its diameter, and calculated from the formula

$$C = .3396\, g d^2$$

in which C = weight of charge, in pounds;
g = specific gravity of explosive;
d = diameter of hole, in inches.

75. Firing Dynamite.—Dynamite is fired with a fuse and cap, or by an electric battery and electric detonator, or

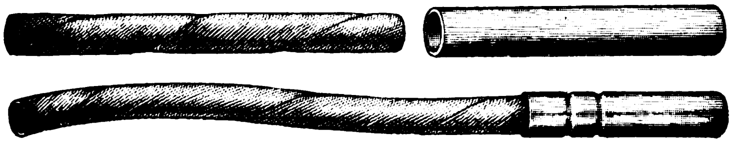


FIG. 6

fuse. The former method is generally adopted for single holes, and the latter where several holes are fired at once, or in a volley.

76. Fuse and Cap Firing.—The cap in this case is slipped over the end of the fuse, after which the upper end is crimped tightly against the end of the fuse with a crimper,

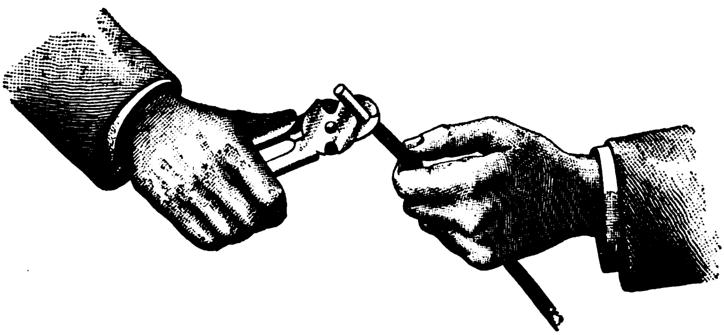


FIG. 7

as shown in Figs. 6 and 7. Miners sometime press the caps on to the fuse with their teeth. This is a very dangerous proceeding and should never be practiced, as one cap exploding in a man's mouth would prove fatal.

TABLE IV

WEIGHT OF CHARGE OF EXPLOSIVE, IN POUNDS

Name of Explosive	Specific Gravity of Explosive g	Diameter of Holes, in Inches (d)												
		$\frac{3}{4}$	$\frac{7}{8}$	1	$1\frac{1}{8}$	$1\frac{1}{4}$	$1\frac{3}{8}$	$1\frac{1}{2}$	$1\frac{5}{8}$	$1\frac{3}{4}$	$1\frac{7}{8}$	2	$2\frac{1}{4}$	$2\frac{1}{2}$
Blasting powder .	1.000	.143	.228	.340	.484	.664	.884	1.148	1.459	1.822	2.240	2.720	3.872	5.312
Carbonite	1.120	.160	.254	.380	.541	.742	.988	1.280	1.630	2.036	2.505	3.040	4.328	5.936
Ardeer powder. .	1.160	.166	.264	.394	.561	.769	1.024	1.330	1.690	2.110	2.597	3.151	4.488	6.152
Blasting gelatine .	1.550	.222	.352	.526	.749	1.027	1.367	1.775	2.256	2.819	3.467	4.211	5.991	8.218
Gelatine dynamite	1.550	.222	.352	.526	.749	1.027	1.367	1.775	2.256	2.816	3.467	4.211	5.991	8.218
Dynamite	1.600	.229	.363	.543	.773	1.060	1.412	1.833	2.329	2.910	3.579	4.347	6.184	8.480

In placing the cap in the cartridge, there is great diversity of opinion as to which of the many ways used is the best. Fig. 8 shows a very common method in which the cap is placed in the top of the cartridge and in the center with only about two-thirds of the cap embedded in the material of the cartridge. This is done to avoid the danger of its igniting the explosive and thus causing deflagration of the cartridge in place of detonation. An objection to a cap placed in the

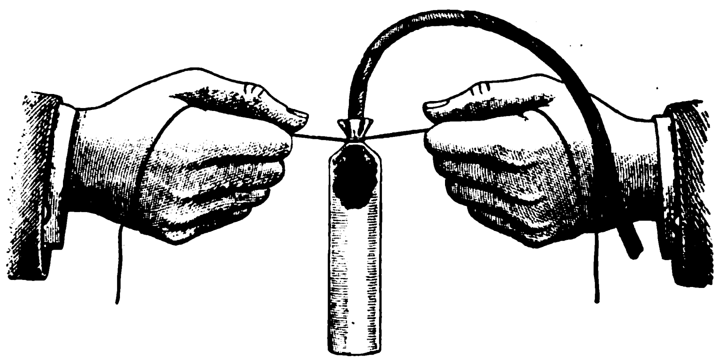


FIG. 8

center of the cartridge is that the fuse is very apt to be bent and injured in the tamping, while it also interferes with the tamping.

77. Instead of placing the cap in the center of the end of the cartridge and tying the end of the paper wrapper about the fuse, as shown in Fig. 8, an inclined hole is made in the end of the cartridge, as shown in Fig. 9, and the cap placed deep down in the charge. Instead of inserting the cap through the end of the cartridge, many manufacturers of explosives strongly recommend placing it in a hole in the side, as shown in Fig. 10. The fuse is tied in two places, a half hitch being taken around it.

A common, but bad, practice among miners is to make a hole in the side of a cartridge, place the cap and fuse in it, and bend back the fuse, as shown in Fig. 11, in order to prevent the cap being pulled out. The sharp bend in the fuse is sometimes sufficient to cause a break in the train of powder, resulting in a misfire.

78. Placing the Cap for Electric Firing.—Figs. 12 and 13 illustrate the method of placing an electric exploder, or cap, in a cartridge of dynamite. The cap *a* is placed either in the bottom, Fig. 12, or at the side of the cartridge, as in Fig. 13, the hole to receive it having been made with a

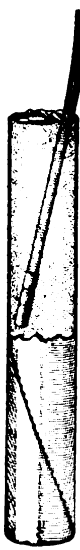


FIG. 9

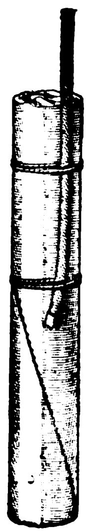


FIG. 10

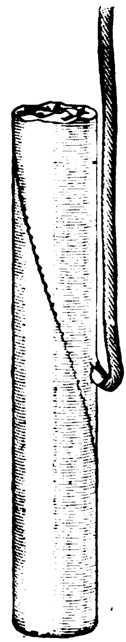


FIG. 11

sharp stick or lead pencil. After this is accomplished, the blasting wires *b* are tied firmly to the cartridge, as illustrated at *c*. In firing dynamite by means of electricity, there is no danger of the wires setting fire to the powder, and hence the exploder can be placed well down in the cartridge. Sometimes, when a long charge in a very deep hole is to be fired, two or more electric exploders are used in the same charge, one cartridge containing an exploder being placed near the bottom of the hole and another at the top. The method of loading holes for firing by electricity is the same as that described for firing with fuses. Care should be taken to prevent the leading wires from coming in contact with the damp earth as much as possible, also that in tamping the hole the wires do not become broken, or the covering materially injured, and that the wires are not brought into contact with each other or with the damp ground.

Many miners have a bad practice of putting the cap of an electric fuse in obliquely and bending the wire over and securing the cap by a half hitch of the wire, as shown in


FIG. 12


FIG. 13

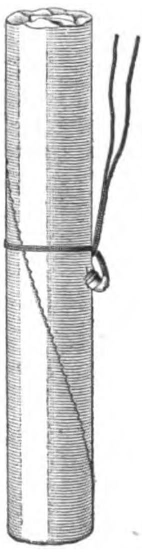


FIG. 14

Fig. 14, or, to make it worse, by two half hitches. So much force is used in making the half hitch that the sulphur filling in the electric fuse is usually broken, sometimes disarranging the wires in the cap and even breaking the fine platinum wire or bridge. In any event, the cement is so broken as to leave free passage into the cap of any water that may be contained in the hole.

The platinum bridge of an electric fuse is very small and delicate in order to be heated red hot by the very small current of electricity that is used to fire the fuses, and any unusual strain on the wires may break the bridge, thus breaking the circuit and causing a failure of the shot.

Furthermore, sharp bending of the copper wires may damage the insulation, very likely leaving bare wires touching, causing a short circuit and a failure of that particular cap. The bared wires, even if they do not touch, offer an opportunity for a short circuit through any moisture present, which will rob that particular cap of part of the current of electricity, while the next cap might get the full current. The result will be that the first cap will miss fire.

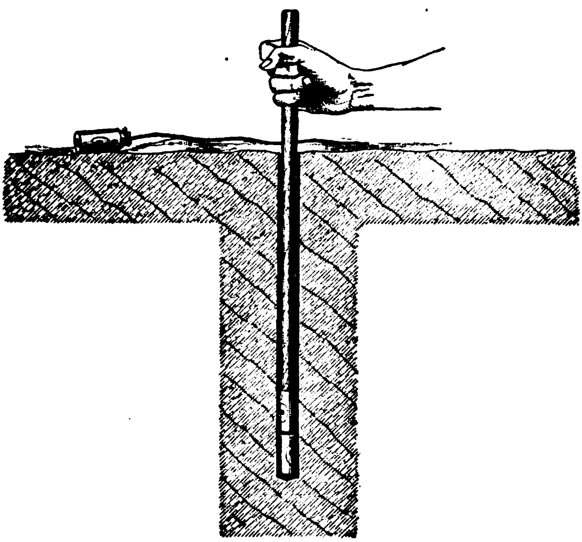


FIG. 15

79. Loading Dynamite.—In loading a hole with dynamite, the cartridges are placed in one after another and pressed, not rammed, into place, preferably with a wooden bar. The cartridge containing the cap is called the primer and is the last one introduced into the hole; it is pressed down until it rests on those already introduced and after this the tamping is pressed lightly on the charge, care being taken not to explode the primer. If the cartridges at hand are not the size required, the paper coverings may be split open with a knife and the material forced to fill the hole with the aid of the tamping bar. It is very important, if the full effect of the explosive is to be obtained, that the part of the hole in which the charge is located be completely filled, and that no air spaces be left between the charge and the walls of the hole.

80. Location of Primer.—The cartridge containing the cap is called the **primer**, and while it is usually the last cartridge to be placed in the hole, it may be placed in the

(a) (b)

FIG. 16

middle of, or even at the bottom of the charge, with the idea of insuring a more thorough explosion. This is theoretically correct since the explosion acts equally in all directions, but while there may be some reason for firing a charge with black powder in this manner, there is no good reason for such practice when firing dynamite, for the explosion of dynamite is so quick that there is no appreciable difference in the results, whether the cap is placed in the top or in the middle of the charge. There is, however, a decided objection to placing the cap in the middle or bottom of the charge when using common fuse, as there is a chance that the fuse will set fire to the dynamite and cause not only a loss of dynamite, but a premature explosion, which cannot be as thorough as if detonated by the cap.

Dynamite is frequently condemned for producing injurious fumes, when, as a matter of fact, these fumes were made by the partial burning of the dynamite before its explosion, the dynamite having been lighted by the fuse before the fire reached the cap. An experienced person can readily distinguish between the fumes produced by burning dynamite, and those produced by detonation.

Fig. 16 (*a*) shows a hole with the primer placed in the center of the charge and in which there is no bend in the fuse, a theoretical arrangement seldom found in practice. Fig. 16 (*b*) shows a common method of placing a charge with the primer on top and the cap placed in the side of the cartridge as illustrated in Fig. 10.

81. Tamping Shot Holes.—The material used for tamping or stemming shot holes should be of such a nature that it is not liable to strike fire while it is being rammed home; that is, any material containing quartz or similar hard rock should be avoided. Clay slightly dried or brick dust sufficiently moistened to make it adhere form the best tamping material for powder. A series of experiments carried out by Sir J. F. Burgoyne as to the best length of tamping to be used in the holes for black powder resulted in the conclusion that 17 inches was the least amount that could be used in a hole 1 inch in diameter, 18 inches of tamping in a hole 2 inches in diameter, and not less than 20 inches of tamping in a hole 3 inches in diameter. His experiments were carried on with clay, brick dust, and rottenstone, the explosive being blasting powder.

82. Tamping for High Explosives.—Such explosives as nitroglycerine compounds, which develop their full power instantaneously, require less tamping than powder, on account of the fact that the shock is delivered on the sides of the chamber with sufficient force to burst the rock before it can have had any appreciable effect on the tamping; hence, for such explosives very light tamping is sometimes used, as, for instance, filling the hole with water, or applying a few inches of fine dirt or sand.

83. Diameter of Holes.—In driving headings or sinking shafts, experience shows that holes having a diameter varying from $\frac{3}{4}$ inch to $1\frac{1}{2}$ inches at the bottom are most economical in hard rock, if charged with the strongest high explosive. On the contrary, holes $1\frac{1}{2}$ to $2\frac{1}{2}$ inches in diameter, and charged with a weaker explosive, are the best when operating in weak rock. All the holes in the heading or shaft should have the same diameter, and the best arrangement is to give an equal resistance of rock to each, and to so place each hole that it will receive the greatest benefit from the free faces formed by firing the previous holes.

FIRING BLASTS

84. Lighting the Fuse.—In firing blasts by means of fuse, where it is desired to have the shots follow one another, the fuses are made of various lengths and then all lighted at one time. If an ordinary fuse is simply cut off on an angle and lighted by means of a match, it is sometimes difficult to start the powder, and on this account the miner may have to leave before he has all the shots lighted. In order to make sure that the fuse takes the fire, the end of it is split sometimes, as shown in Fig. 17, and a small wedge or piece of giant powder *a* is introduced into the split. When giant powder is lighted,

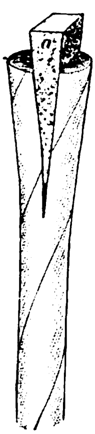


FIG. 17

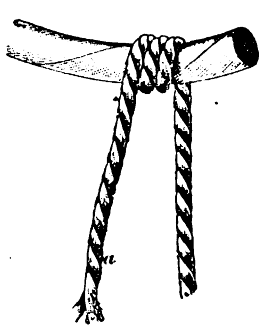


FIG. 18

it burns with a bright and fierce flame, and hence a small piece burned at the end of the fuse is almost sure to properly ignite it. Another scheme is to use pieces of candle wicking dipped in kerosene, which are twisted about the end of the fuse, as shown at *a*, Fig. 18. After all the blasts are ready and the fuses in place, these pieces of candle wicking are adjusted, and the miner can light them all very quickly by simply passing his lamp from one to another. The burning oil on the candle wicking ignites the fuse.

85. Electric Blasting.—The method of electric blasting, as used in America, depends on the generation of a current of electricity by means of a small magneto-electric machine, which is really a small dynamo, the armature of which is made to revolve rapidly between the poles of the field magnets by means of a crank or by a ratchet.

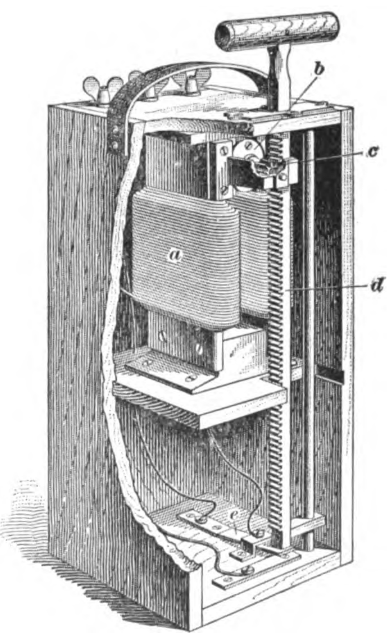


FIG. 19

86. The Electric Battery.—The machine shown in Fig. 19, commonly, but incorrectly, called a *battery*, is in common use in America for firing blasts. *a* is the field magnet; *b* an armature that revolves between the poles of the field magnet; the loose pinion *c* (the teeth of which engage the rack bar *d*) is arranged with a clutch, so that as the rack bar descends the pinion causes the armature *b* to rotate and generate a current. During the down stroke of the rack bar, the connections are such that the current flows inside the machine without affecting the outside circuit. The current increases in strength until the rack bar strikes the spring *c*, which changes the connections so as to send the full strength of the current into the outside circuit and through the caps for firing the blasts.

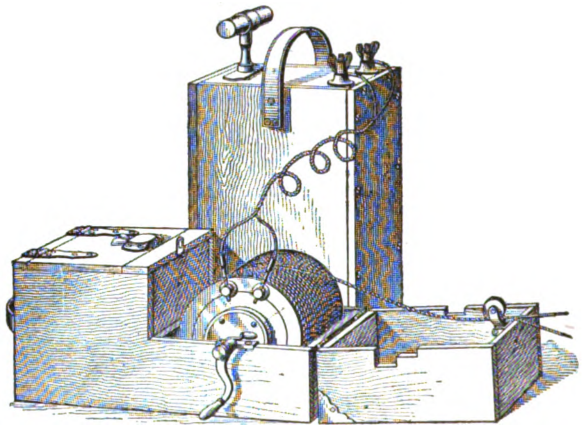


FIG. 20

Fig. 20 shows the battery attached to a reel on which the firing cable is coiled. This cable consists of two insulated wires twisted together into a single cable.

87. Connecting Wires.—To connect the ends of two wires, scrape off the insulation for about 2 inches from each end and scrape the wires clean and bright. Then twist the ends together, as shown in Fig. 21. It is very important, to prevent misfires, that all connections are clean and well made, as one bad connection may cause all the holes to misfire.

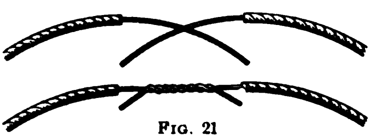


FIG. 21

88. Connecting Up and Firing the Blasts.—After the holes have been loaded, the fuse wires are left projecting from the hole, and are joined by connecting wires in such a manner as to leave one free wire at each end of the series to be fired, as at *b*, Fig. 22, *a* being fuse wires leading downwards to the charges to be fired. After all is in readiness, the leading wires are connected to the loose ends *b*, and when every one has left the vicinity of the blast, the other ends of the lead wires or cables are attached to the blasting machine. Some blasting machines are provided with three screws on the outside, to which leading wires are attached. When

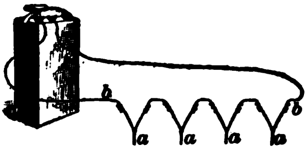


FIG. 22

only a small number of blasts are to be fired, one of the lead wires is attached to the middle screw and the other

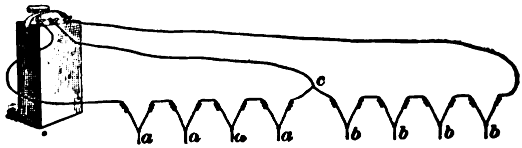


FIG. 23

to the outside, as illustrated in Fig. 22. When a large number of blasts are to be fired the lead wires are arranged as shown in Fig. 23, *a* being one series of charged holes, and *b* another. The wires on the outside are attached to the ends of the entire series, as in the previous case, while the wire from the central screw is attached to the center of the series of connecting wires, as at *c*. By this arrangement, a large number of blasts can be fired with a single battery and the size of the lead wires very much reduced.

FIG. 24

Fig. 24 shows a man in the act of firing a blast. This is accomplished by lifting the handle of the magneto-machine to its full height, and pushing it downwards slowly for the first ½ inch or so and then with full force, until the rack attached to the handle reaches the bottom of the box and sends the current through the caps in the holes.

When firing a hole by means of a battery, the handle, or rack bar, should never be churned up and down, but should simply be given one vigorous stroke, as directed. Most batteries are made to fire with a downward stroke, but some fire with an upward stroke of the handle. A battery should always be kept clean and never abused or played with. Its strength should be tested from time to time by means of a test lamp or galvanometer. Test galvanometers are used to ascertain if any breaks exist in the circuit and the fuses.

89. Remarks on Firing Blasts by Electricity.—To insure success in firing a blast by electricity, the following points should be observed:

1. Battery wires and primers should be suitable to each other; never use two kinds of primers in the same blast.
2. The battery should be of sufficient power to fire all the caps or primers connected at one time; do not attempt to load a battery to its full limit.
3. The electric fuses or primers should be kept in a dry place, and everything kept as clean as possible.
4. All the joints at connections and points of contact of the wires should be well made so that the wires cannot separate, and the surfaces should be clean; also see that the joints in one wire do not touch those in another, and that bare joints do not touch the ground.
5. Do not kink or twist the wires so as to cut the insulation during the process of tamping. (If the insulation is cut, the fuse is useless for wet ground or a wet hole and should be laid to one side.)
6. The operator's hands should not touch the terminals of the battery when firing.
7. The battery should not be connected to the leading wire or cable until every one is in safety.
8. The wire connections should be bound with insulating tape in damp places to avoid leakage and short-circuiting of the current.

90. Firing From Dynamo.—In sinking the Parker shaft at Franklin Furnace, New Jersey, after the shaft was down a few hundred feet there was more or less water to contend with, and considerable difficulty was experienced in firing the blasts with a magneto-machine. To overcome this, a line was taken off from the dynamo that was used for lighting the buildings and surface around the shaft, and also for lighting up the shaft itself. This line was carried from a block

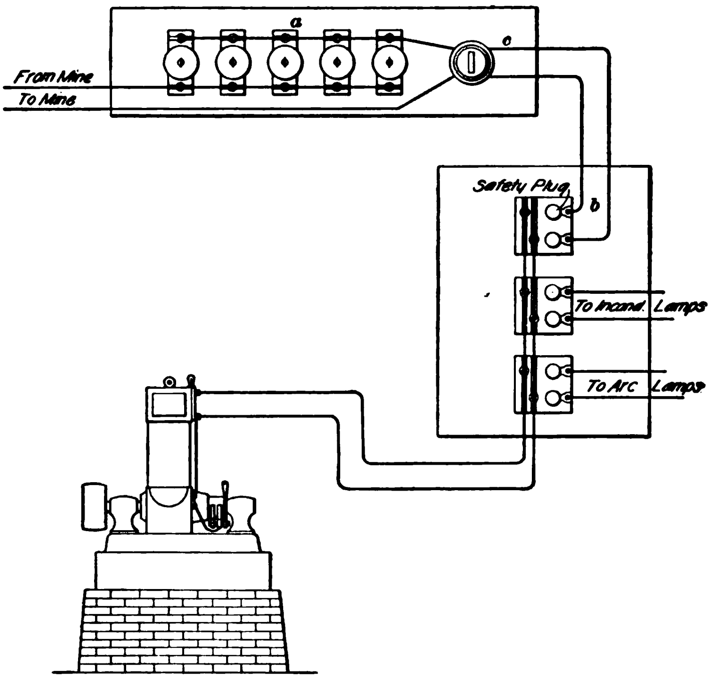


FIG. 25

containing two safety plugs *b*, Fig. 25, to a board. One snap switch *c* was introduced and the positive line continued directly to the mine. The negative line was connected up through five incandescent lamps *a* to reduce the current. A little experimenting was necessary to determine the proper number of lamps to put in so as to reduce the current sufficiently. One of the safety plugs was always taken out and kept in a drawer, so that should any one turn the snap switch while the men in the bottom of the shaft were connecting up the holes for the blasts, it would be impossible to fire the blasts, as the line was cut off at this plug. When ready to blast, the foreman and his men, after removing all the tools, came up to the surface and signaled to the engineer that he was ready to "fire," whereupon the engineer took the safety plug from the drawer and inserted it in the block. He then turned the switch *c* and the blast was discharged. After this device was installed, there was no more trouble from imperfect blasts. The arrangement of wiring, etc. is shown in Fig. 25.

PRINCIPLES OF ROCK BLASTING

91. Blasting Operations.—Rock blasting consists in breaking rock from the solid stratum by means of an explosive. When an explosive is discharged in a confined space, the suddenly expanded gases press against the confining walls; and if the force is sufficient to overcome the cohesion of the material composing the walls, the rock will be ruptured, or there will be what is termed *a blast*. The several blasting operations are drilling, charging, tamping the hole, and firing the blast.

92. Maximum Force of a Blast.—By experience, it has been proved that the maximum pressure or effect that any explosive substance can develop is that obtained when it is detonated, or exploded, in a space that it entirely fills; that is, in a space equal to its own volume. Hence, to obtain the greatest effect from a blast, the charge should entirely fill the hole up to the tamping.

93. Effect of a Blast.—If the right amount of explosive is used, there will be a deep boom and the rock will not be thrown with great force from the solid. If too much powder is used, there will be a sharp report and the surplus explosive will throw the broken rock away from the solid and shatter it badly. If insufficient explosive is placed in the drill hole, the rock will not be broken, but the tamping will be blown from the hole just as a bullet is shot from a gun, producing what is known as a **blown-out shot.**

In mining soft cleavable minerals, powerful explosives are not generally used, their effect being such as to shatter; on the other hand, in tenacious minerals, powerful explosives are used for their shattering properties. Less powerful explosives, such as gunpowder, are used where a rending action is desired such as in mining coal, but they are not desirable in tough ore formations because they break down the mineral in large pieces that, to be handled, must be block-holed and reblasted.

94. Power of an Explosive.—While the power of most explosives can be calculated, the theoretical power can never be obtained in practice. The factors that enter into the problem vary so widely and are so numerous that seldom can exactly similar results be obtained from blasts fired apparently under similar conditions.

The weight of a mass of rock opposes the action of a blast, and this weight is assisted by the atmosphere that presses on it with a weight of 14.7 pounds per square inch at sea level.

In case the hole is damp or wet or the rock cold, it will decrease the heat produced by the discharge and the power of the explosive. Slips, joints, and cleavage planes affect the blast as do also texture and structure of the rock. The shape and location of the drill hole and the method with which it is charged and tamped are important factors.

95. Rock Structure and Texture.—Brittle rocks are easily fractured, while strong, compact rocks in which the cohesive powers are great are much harder to break. Plastic materials, like fireclay, which are neither brittle nor tenacious, are very difficult to blast.

96. Influence of Fissures or Joints and Bedding Planes on Blasting.—Fissures or joints and bedding planes, when open, have something the effect of free faces, and as a consequence they influence the best position for placing a blast. When possible, the charge of explosive should never be placed in contact with a fissure or bedding plane, but should be located in the firm rock, in order to avoid the escape of the gases through the fissure, that would thus reduce the effect of the blast. If it is possible to avoid it, a drill hole should not cross crevices and slips.

97. Elasticity and Porosity of Rocks.—Since compact and brittle rocks have little elasticity, their limit of elasticity will be reached when they have undergone very slight extension; hence, there is no appreciable enlargement of a drill hole in such rocks before rupture takes place. With porous rocks or sand, the blast tends to solidify the rock and fill empty spaces, thereby increasing the size of the drill hole and decreasing the force of the explosion.

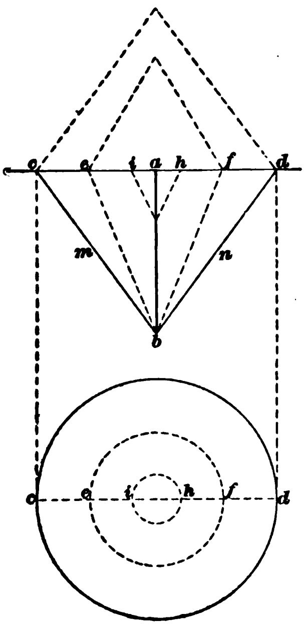


FIG. 26

98. Form of Cavity.—The form of cavity produced when a single drill hole is fired is usually that of a cone; thus, in Fig. 26, if *a b* represents a vertical drill hole, the rock broken would theoretically have the form *c b d*, the line *c d* being the diameter of the base of the cone. In case the strength of the explosive was not sufficient to overcome the tenacity of the rock to so large an extent as represented, it might form a base *e f*, or be merely a blown-out shot with the base *i h*. From a practical standpoint, a position perpendicular to the face is the worst position in which a drill hole can be placed, as there is but one free face *c d* for the force of the blast to break, since any pressure exerted in the direction of *m* or *n* is opposed by solid rock. Since reaction is always equal to action, the line of least resistance must be along the line representing the resultant of the forces acting on *n* and *m*, or the drill hole *a b*.

99. Inclined Holes One Free Face.—A **free face** is the exposed surface of a mass of rock. Fig. 27 shows the hole *a b*, put in at an angle to the free face *c d*. This is a better method of placing a hole than that described in Art. **98**, from the fact that the line of least resistance *e b*, is not in the direction of the hole, but perpendicular to the face *c d*. A charge of powder placed in an inclined hole will therefore break more rock than a similar charge in a hole of the same size and depth perpendicular to the free face. The limiting inclination of the hole is 45° with the free face; a hole at a less inclination will break less and less rock as the line of the hole *a b* will continually approach the line *c d*, and will become zero when the powder is placed on the top of the ground.

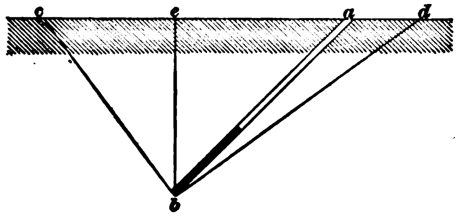


Fig. 27

100. Effect of Free Faces in Rock Blasting.—The more free faces there are, the greater will be the ease with which an explosive will accomplish its work. Fig. 28 is a cross-section showing a hole *a b* placed in a rock having two free faces *C* and *D*. If there were but the one free face *C*, the force from the charge at *b* would break out the cone or crater *e b g*; if the face *D* were the only one exposed, the charge *b* would break out the crater *e b j*. With the charge *b* equally distant from the faces *C* and *D*, and of just the right size, the bounding surface between the two craters will coincide in the line *b e*, but since the force of the explosion at *b* is divided between the two craters

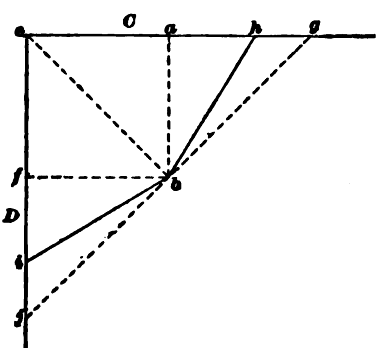


Fig. 28

and a portion of it is reflected by the solid rock, the crater actually broken out will be approximately *h b i*, that is, a crater that is not equal to the sum of the two craters *e b g* and *e b j*.

If the charge *b*, Fig. 29, is located so that *b f* is greater than *b a*, the force acting on each face separately will break the craters *g b k* and *j b l*, the wedged-shaped piece *e k b l* not being included in either. With the charge *b* acting on both faces *C* and *D* together, part of the force is used in breaking down the mass *e k b l* and the crater broken out is bounded by the lines *h b i*, instead of by the lines *g b j*.

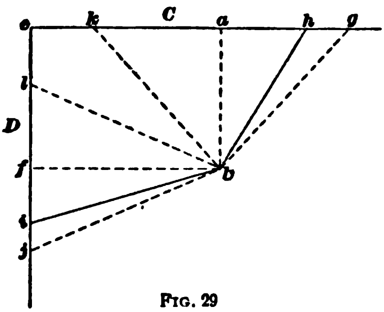


FIG. 29

Similar reasoning may be applied to any increase in the number of free faces. The greater the number of free faces the larger amount of material can be broken down with a single shot; or what amounts to the same thing, a smaller charge will do the same amount of work, the greater the number of free faces, but the increased amount of material loosened will not be proportional to the increase in the number of free faces.

101. There is a general rule that the longest line of resistance should not exceed three-halves of the shortest line of least resistance if the maximum effect of the explosive is to be obtained. If possible, the shots should be placed so that the shortest line of resistance is horizontal and the longest vertical so that the weight of the rock may assist the breaking down.

It is evident, therefore, that in blasting it is advantageous to have as many free faces exposed as possible, not only on account of the decrease in the amount of powder required, but also because it is possible to obtain the material blasted in larger lumps than when blasting is done with a single free face. This is advantageous particularly in coal mining where the lump coal is more valuable than the fine coal.

Fig. 30 shows the method of undercutting adopted by soft-coal miners previous to their blasting, to secure two free faces; also the location of a shot to bring down the coal. Metal miners frequently have recourse to the same plan and when the stuff is too hard to undercut with the pick, shot holes are sometimes put in and the undercutting done with powder.

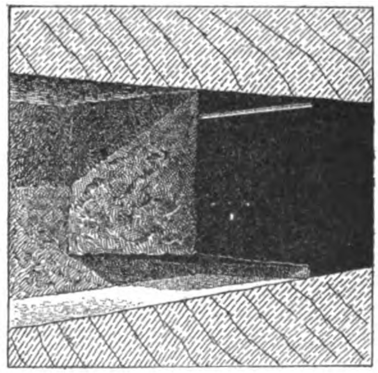


FIG. 30

102. Relation of Diameter of Hole to Line of Least Resistance.—If the diameter of the hole *a b*, Fig. 28, remained the same, and the line of least resistance were increased, a place would soon be reached where the charge of explosive would fail to break out the rock. It is not good practice to have a powder charge occupy more than one-half the hole; hence, in order to increase the effect of a charge the diameter *a b* of the hole should be increased; that is, as the distance *j b* increases, the diameter of the hole *a b* must be increased; or there must be a chamber formed at the lower end of the hole in which the powder charge is to be contained, so as to increase the size of the cone of throw toward any free face. This chamber is sometimes formed by using some form of expansion bit or reamer, but the usual custom is to introduce a small charge of high explosive that will enlarge the end of the hole, as shown in Fig. 31. By continuing this process, an opening of sufficient size to contain the desired charge may be formed. This operation is called *chambering* or *squibbing*. Where large masses of soft material are to be loosened,

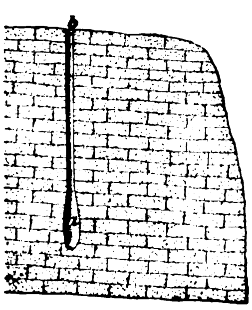


FIG. 31

it is common practice to use dynamite or nitroglycerine for chambering the hole and black powder for the blasting. Holes are sometimes drilled as much as 20 feet deep and several kegs of powder introduced into the chamber formed by firing the high explosive. This method of blasting is used in open-cut ore mines, milling, and in steam-shovel mines; also in side cuts of earthworks.

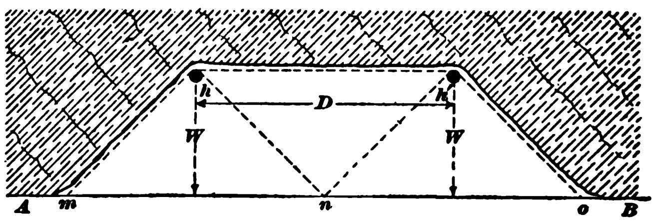


FIG. 32

103. Effect of Firing Several Holes Simultaneously.—Fig. 32 represents two drill holes *h*, *h'* drilled at a distance *W* from the free face *A B*. If these holes were fired independently, each would break out approximately the same amount of material, as *m h n* or *n h' o*. If they are fired together, and the distance *D* between them is not too great, they will bring out the entire mass *m h h' o*. It will be seen from this that by firing two holes together an additional amount of rock *h n h'* has been broken with the same amount of powder required to break the two masses *m h n* and *n h' o*. The distance *D* between the holes must be varied according to the character of the rock. In comparatively soft material it is less than in hard rock though probably the limit is twice the distance *W*.

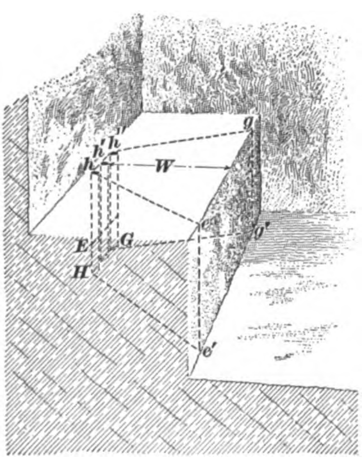


FIG. 33

Fig. 33 illustrates another case. Here three holes h, h', h'' have been drilled close together, and each one loaded with a charge the depth of which will be represented by HE. Any one of the holes, if fired separately, would not be able to break through the distance W, but, by firing the three together, the mass $e h h'' g g' G H e' e$ may be removed at one shot. By this means, greater masses of rock can be removed with smaller drilled holes than would be possible were it not for the combined effect of the several charges.

104. The form of cavity and the amount of material dislodged by a shot, as described in the preceding articles, are largely theoretical and no universal rules can be given. Experience is the only safe guide in choosing the location and size of the holes and the amount of the charge of explosive, and an experienced miner will study the character of the rock to be blasted so as to place his holes at such an angle that he may get the maximum effect from them and avoid blown-out shots, and take advantage of slip and cleavage in the rock.

BLASTING IN DRIVING TUNNELS

105. Arrangement of Drill Holes.—In driving rock tunnels, the chief item of cost, under ordinary circumstances, is that of drilling. Where machine drills are used, there will be more or less time consumed in shifting machines, for which reason it is deemed advisable, wherever headings are large enough, to use two machines and if possible on one column. This is frequently also the case in shaft sinking. The machines should be so placed that the holes may be drilled methodically, so as to economize in powder and time.

In tunnel driving and in shaft sinking, there is always one free face, and in order to obtain two free faces it is necessary to first take out a cone or wedge of rock from the center or side of the heading. Holes put in for this purpose are termed **key holes**, or **cut holes**, and are fired simultaneously in order to obtain the best effect of the powder and to save time. In making key holes, the size of the heading and the hardness of the rock are to be considered. There is always one of three cases to consider, as powder is used in soft, medium, and hard rock. In soft rock, key holes in the bottom may be the best.

The key holes may be arranged in circular form to take out a cone and the outer holes are then arranged more or less concentrically with the center cut holes, or more frequently the key holes are arranged in straight lines from top to bottom of the face so as to take out a wedge-shaped center cut, and then the enlarging holes are similarly arranged in straight lines parallel to the lines of key holes.

106. American and European Practice.—It is customary in some European countries to place the breaking-in holes so that they will not meet, in order that there may be a wide end to the cavity broken out by them; American practice, however, is to make them meet so that the increased quantity of powder that may be inserted will have more effect. European practice is generally to use short holes, that is, one-half the width of the heading, while American practice is to make the holes about as deep as the heading is high. While the two systems call for about the same number of feet of drill hole, there must necessarily be considerable saving in time where drills are not changed as often as is required in European practice.

The American system is probably the better where labor is expensive, since it permits of quicker advance and keeps the shifts up to their work in better shape. It requires, however, more explosive, and is therefore best adapted for countries where explosives are cheaper than labor.

107. Conical Center Cut.—Fig. 34 (*a*) shows a rock heading 6 feet by 7 feet in medium-hard homogeneous rock. The key holes *1* are put in at an angle so that the bottom of the holes will meet at a depth of about 6 feet from the face. Fig. 34 (*b*) shows a section of (*a*). Where drill holes meet in this manner, they form a chamber in which the powder can be placed in larger quantities and be more effective than in single drill holes. The direction of the second rows of holes is shown at *2*, and the third row at *3*. The holes are all drilled in one shift, and the blasting done and the broken rock removed by the following shift. It is customary to charge and blast the holes by rounds, *1* being first fired, and as soon as rock is cleared from this the enlarging holes *2*

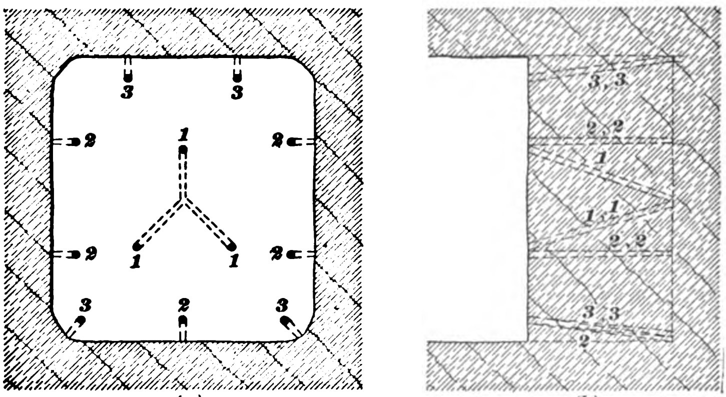


FIG. 34

may be charged. It is sometimes customary to fire holes *2* and *3* together, but it is better to fire *2* and remove the dirt, and lastly *3*, as that gives a larger free surface to work on. There must be a wait, after each round is fired, for the air to change, but with an air hose the foul air can be driven out quickly, and while the rock is being removed the next round may be charged. The number *3* round is known as the squaring-up round, and while the holes are placed a short distance from the roof and floor they are kept, as nearly as is possible, parallel with the side walls. That they are not put in exactly horizontal is due to the inability of the drill runner to place the machine nearer the walls. The number and position of the drill holes for enlarging will depend on the size of the heading and the explosive used.

108. Fig. 35 (*a*) and (*b*) shows another arrangement where the rock is hard. The key holes *1* in this case are four in number and outside of them are four enlarging holes *2*. It might be possible to load and fire holes *3* and *4* together, but as the latter are in tension and the number *3* holes are assisted somewhat by gravity, better results will

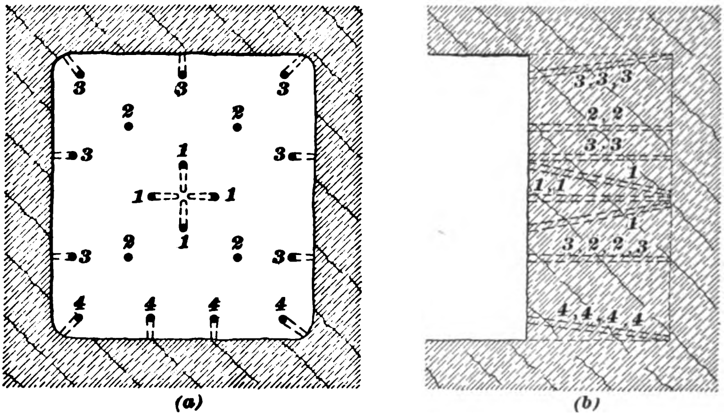


FIG. 35

probably be obtained by firing number *4* holes last. It is to be understood that what has been stated is not always the proper way to place holes; much depends on the force of the explosive, the hardness of the rock, and the evenness of its texture. The miner must be guided largely by experience and common sense, in finding exactly the best position. To drill extra hand holes for squaring up a heading is unsatisfactory and expensive, consequently the key holes that furnish two free faces are the particular ones to be watched. Key holes should be placed as far apart as experiments show it to be necessary to give the best results, and when that distance has been found, it should not be varied.

109. Square-Cut Drilling and Blasting.—By this method, a center cut is taken out the full height of the face and all subsequent holes are drilled in lines parallel with the side of the heading. Fig. 36 (*a*), (*b*), (*c*), and (*d*) illustrates the square-cut method driven according to the European method of blasting; that is, the holes are not more than one-half the width of the heading in depth. Fig. 36 (*a*) shows the face of the heading; Fig. 36 (*b*) and (*c*), horizontal sections; and Fig. 36 (*d*), vertical section.

Two or four drills can be used to advantage in drilling the holes for the square-cut system. With strong hard rock, the diameter of the holes will be about $1\frac{1}{8}$ inches at the bottom, but the four holes *1*, *2*, *3*, *4* will be somewhat shallower than the others. It will also be noticed that there are only three

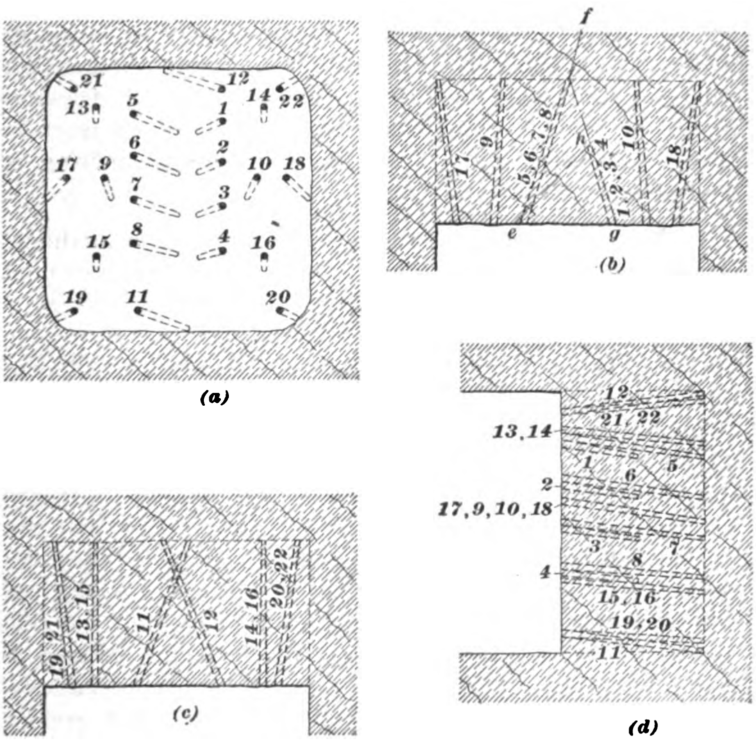


Fig. 36

upwardly inclined or dry holes to be bored in this arrangement, as compared with four in the center-cut system, Fig. 34, and four in Fig. 35. As the drill holes are always slightly conical (owing to the fact that each succeeding drill is of smaller diameter than the preceding), the four shallower holes will be nearly, if not quite, $1\frac{1}{4}$ inches in diameter at the bottom. The entering wedge, Fig. 36 (*b*), is best removed in two stages: First, the part *egh* by the breaking-in shots *1*, *2*, *3*, and *4*, and then the part *efh* by the breaking-in shots *5*, *6*, *7*, and *8*. The order of firing the shots is as follows: First volley, *1*, *2*, *3*, and *4*, simultaneously; second volley, *5*, *6*, *7*, and *8*, simultaneously; third volley, *9*, *10*, *11*, and *12*, either simultaneously or consecutively; fourth volley, *13*, *14*, *15*, and *16*, either simultaneously or consecutively; fifth volley, *17*, *18*, *19*, and *20*, either simultaneously or consecutively. The effect is practically the same whether the enlarging shot holes are fired simultaneously or consecutively, on account of the fact that they are too far apart to assist each other, but to save time simultaneous firing is advisable.

110. To compare the European and American methods, assume the heading to be 7 feet square; the European method requires 48 feet of drilling for the center holes and 35 feet of drilling for the remainder of the holes. If 1″ × 8″ cartridges are used, the holes will be $1\frac{1}{8}$ inches in diameter, and will contain, if they are loaded half full and rammed properly, 18 pounds of powder. In the American method, there will be 92 feet of drilling—56 feet in the center holes and 36 feet in the squaring-up holes. These holes will average $1\frac{1}{4}$ inches in diameter and use $1\frac{1}{8}$″ × 8″ cartridges. If now they are loaded half full of powder and rammed properly, they will require 23 pounds. The difference in the cost of explosives will be about $1 in favor of the European method, but this saving would be more than offset by the extra shifting of drills and labor lost thereby. With the American system, there is greater concentration of work and greater advancement.

111. Side Cut in Heading.—Sometimes there is a natural parting at one side of the heading, as when the heading is following a vein of ore, or a slip in the rock. In such a case, the side cut offers very important advantages, and especially when only one rock drill is employed. Fig. 37 illustrates a set of holes drilled to make an advance of 3 feet

6 inches in a heading by means of a side cut. The order of firing would be as follows: First volley, *1* and *2*, simultaneously; second volley, *3*, *4*, and *5*, consecutively; third volley, *6*, *7*, and *8*, consecutively; fourth volley, *9*, *10*, and *11*, consecutively.

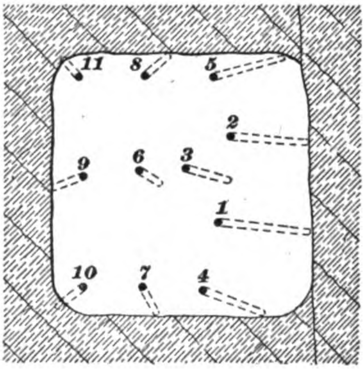


FIG. 37

112. Special Arrangement for Throwing Broken Rock From Face.—Of course, no general rules can be laid down for drilling holes under all circumstances, as the rock may vary from point to point in the same drift or heading, and the seams or joints will always have an effect on the results. Fig. 38 illustrates a set of holes drilled in the face of a heading, which brings out another principle. In this case, the holes are fired in the order of their numbers, the holes *E* being fired last. It will be noticed that there has been an extra

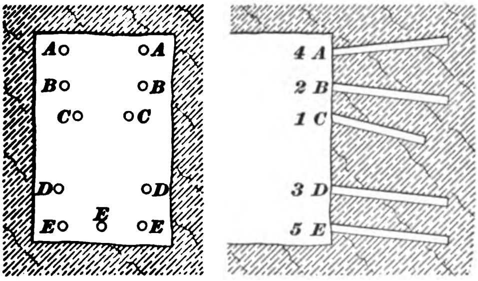


FIG. 38

hole placed at the bottom, and these bottom holes are sometimes overcharged in order that the last shot may have a tendency to throw the broken rock away from the face. If the order had been reversed, and the upper shots fired last, the broken rock would be piled against the face of the heading in the very place where the drill would have to be set up for the next operation, and much valuable time would be lost in throwing back the broken material before the machine could be set up.

113. Extra Heavy Blasts.—In blasting in stopes or open cuts, special methods are sometimes employed, as, for instance, in the large stopes of the hard-ore mines, or for stripping off the surface, where the diamond drill is sometimes employed for drilling blast holes. These holes are drilled 20 or more feet in length and at an angle, so that the end of the hole is sometimes 8 or 10 feet from the face to be blasted, as shown at *a*, Fig. 39. The holes are then loaded

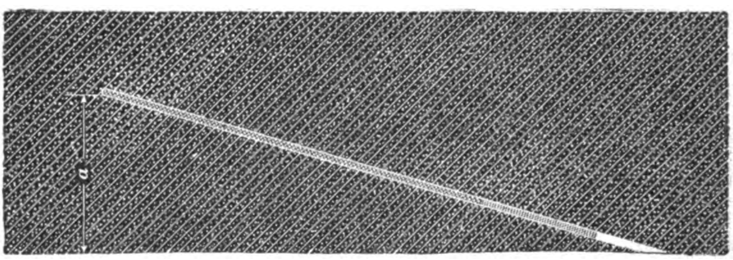


Fig. 39

with 30 to 100 pounds of dynamite and fired. The drilling per foot is much more expensive than it would be if performed by rock drills, but the amount of material broken per pound of powder and per foot of hole drilled is very much greater than would be the case were smaller charges and shorter holes employed.

BLASTING IN SHAFT SINKING

114. In shaft sinking, the general and relative positions of the holes, and their depth, is about the same as for tunneling in similar rock. A center cut is usually made as shown in Fig. 40, and side holes are driven in lines parallel to the holes for the center cut, as shown. The dimensions given in Fig. 40 are for a shaft sunk in white crystalline limestone. At first, 6-foot cuts were made, but later 10-foot cuts were made and the holes arranged as shown in Fig. 41.

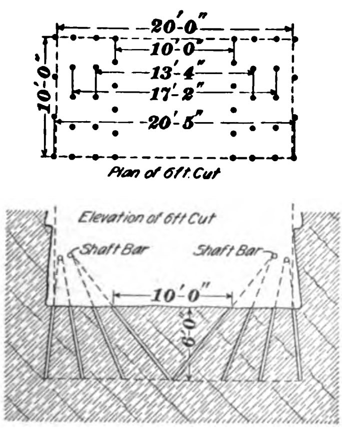


Fig. 40

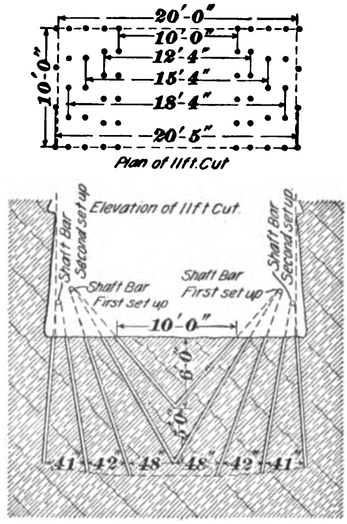


Fig. 41

Further details in regard to tunneling, shaft sinking, and blasting in coal will be found in *Drifts, Slopes, and Shafts*, and *Methods of Working*.

COAL-CUTTING MACHINERY

GENERAL PRINCIPLES OF MACHINE COAL CUTTING

INTRODUCTION

1. Cutting the Coal.—The most expensive and difficult operation in the production of coal is, in general, the process of loosening it from its solid state. This is accomplished in three ways: (1) By blasting it from the solid, as is done in most of the mines in the anthracite regions and in many bituminous mines. (2) By undercutting and blasting or wedging down, or letting the weight of the roof break the coal; this method is used in many bituminous mines worked on the room-and-pillar system, and in all longwall workings. (3) By shearing the coal, either in the center or on one rib, and blasting. In some mines, the coal is both undercut and sheared, either on account of a frail roof or to produce a larger proportion of lump coal; for when the coal is both undercut and sheared, it can be brought down with a very light charge of powder.

2. The many machines that have been constructed to undercut and shear coal are now so perfected to meet the various requirements found in the different fields that an increasing number of mines each year is being equipped with coal-cutting machines. The use of these machines enables the operator to increase his output with a given amount of labor and reduce the cost of production, and permits the operation of a mine with a smaller number of skilled miners.

Results obtained in machine mining have generally been satisfactory wherever the machines have been installed with prudence; that is to say, wherever the proper type of machine has been carefully considered and good judgment used in deciding whether or not machines should be used at all. There are cases in which plants have been installed where the conditions were strongly against the use of machinery, and failure was to be expected.

3. **Conditions Favoring Use of Machines.**—A level even floor, good roof, and good quality of coal, or a soft mining dirt underlying the seam, and a thickness of coal not less than 3 feet, are the chief conditions that favor the use of mining machines.

4. **Conditions Adverse to Machines.**—Coal-cutting machines cannot be successfully employed on irregular seams, or seams of too great inclination, or in seams much less than 3 feet in thickness, or under a roof that requires timbering too near the face, or where the roof pressure is excessive. When the dip in the coal is over 14°, most manufacturers do not care to run the risk of failure and do not recommend machine mining. The pick machine can be worked on a much steeper grade than the chain breast machine, and there are records of its being used on a grade of 23°, but at a much greater cost than for hand-pick mining. The coal must be comparatively hard, and should not crumble nor contain too many boulders or sulphur balls.

A soft bituminous seam of coking coal may be profitably and successfuly mined where the roof and floor will permit, but where the roof or bottom is tender and a great deal of timbering is required, machines are not usually as successful as hand mining.

When drawing pillars, undercutting machines can be used successfully only where the roof, floor, and coal are of good quality, and they cannot generally be used with safety where there are slips or joints in the roof supported by the pillars, or where there is an excessive load on the pillars. In the long-wall system, machine mining is out of place where the roof or floor is so soft that the pack walls are not sufficient to prevent squeezing; on the other hand, where the roof and floor are of average hardness and the pack walls are sufficient, machine mining has an advantage over pick work.

5. Effect of Mining Rate on Use of Machines.—The advisability of mining by machines can be decided only after a complete investigation of the particular mine in question, as local considerations often affect the decision. One especially important item of this character is the mining rate in the district. In a district where the rate for pick mining is low, the introduction of machines may be of no advantage.

TYPES OF COAL-CUTTING MACHINES

6. The most successful coal-cutting machines may be included under two types: (1) Those that act percussively

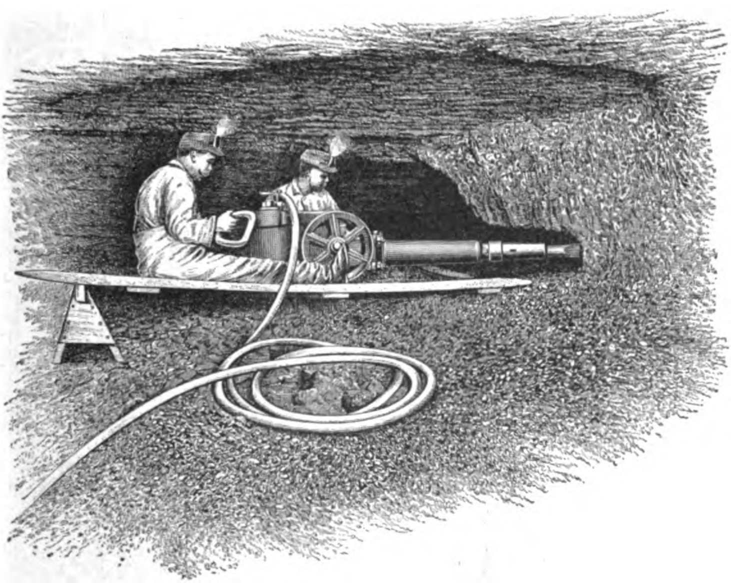


Fig. 1

and cut with a single large chisel, very much like percussive rock drills; these are the *punchers* or *pick machines*, Fig. 1. (2) Those that cut with a series of steel teeth that grind or

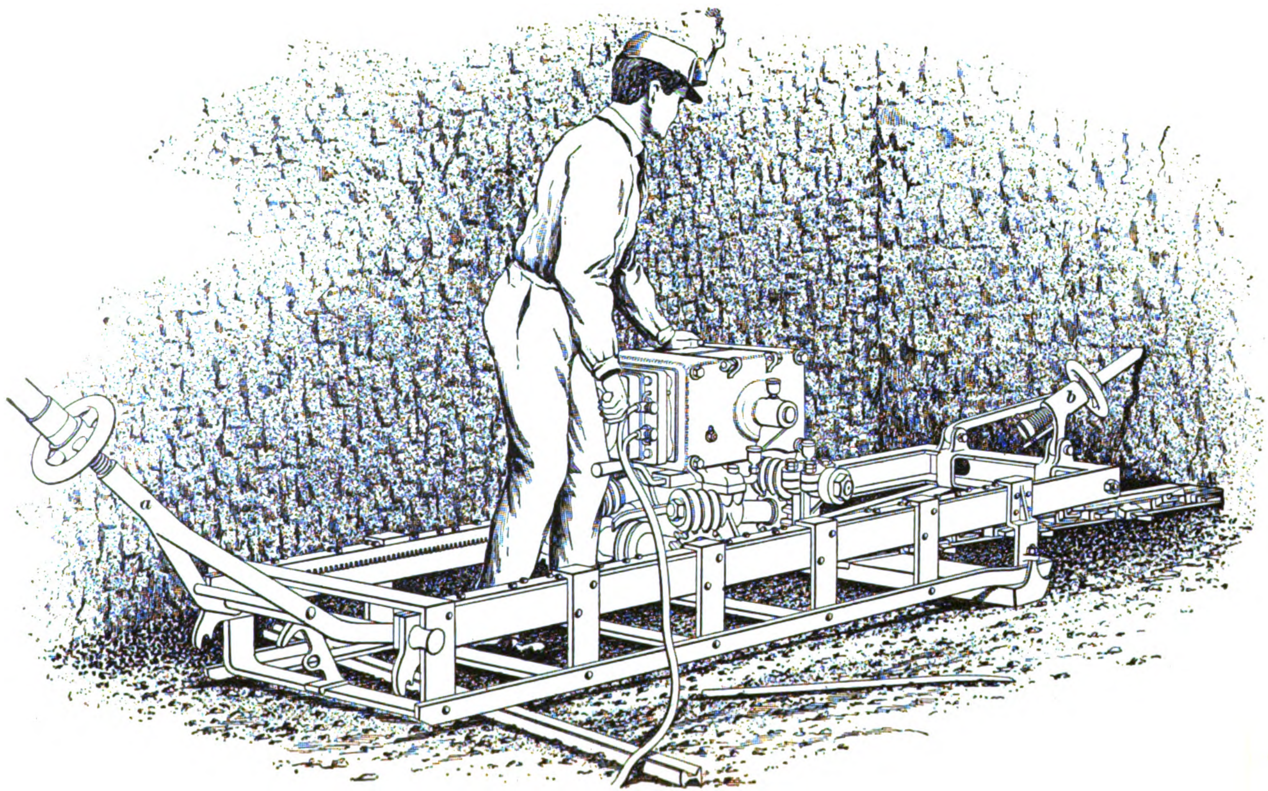


FIG. 2

cut their way into the coal; this class may be divided into four subclasses: (*a*) the *chain* or *chain breast machine*, Fig. 2, which has a series of steel teeth mounted on an endless chain, moving in one direction, by which the teeth are made to cut the coal continuously; (*b*) *cutter-bar machines*, Fig. 22, which have the teeth set in a rotating bar that is made to advance in a direction at right angles to the bar as the teeth cut the coal; (*c*) *disk machines*, Fig. 19, which have the teeth set in the periphery of a wheel that rotates and advances as the cutting progresses; (*d*) the *Stanley header*, Fig. 28, which cuts out a large cylinder of coal and is used almost exclusively for driving headings.

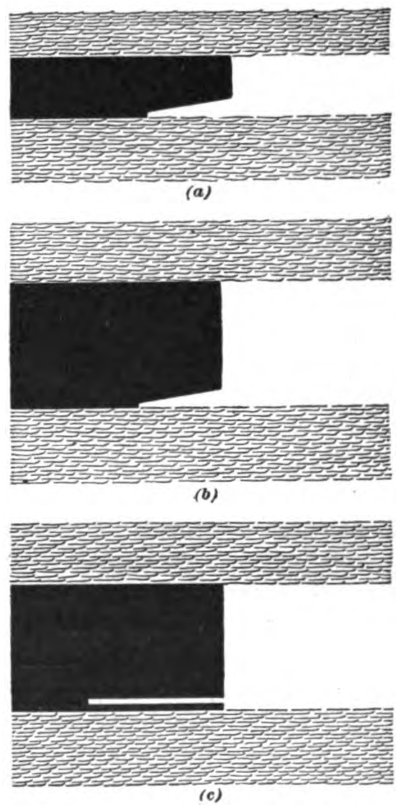


FIG. 3

FORM AND DEPTH OF UNDERCUT

7. Fig. 3 (*a*) shows the form of undercut made by hand-pick mining; Fig. 3 (*b*) shows that made by the pick machine, being practically the same as (*a*); while Fig. 3 (*c*) shows the undercut made by the chain machine. The depth of undercut depends to some extent on the type of machine employed. A common rule, however, is that the coal should be undercut to a depth about equal to the thickness of the seam, except in very thick seams. Where the coal is undercut and sheared, it will not stand so great an amount of undercut, as when it is not sheared. The coal structure and pressure from roof and floor also influence the depth to which the undercut is to be made.

8. The **pick machine**, Fig. 1, imitates in its operation the hand process of undercutting, as shown by the form of undercut, Fig. 3 (*b*). The pick is driven forwards with a blow varying from 1,200 to 1,500 pounds, and the machine delivers from 150 to 250 blows per minute. It cuts from 4 to 6 feet deep with a height of from 12 to 14 inches at the face and from 2 to 3 inches at the back of the cut.

9. The **chain machine**, Fig. 2, makes an undercut of but 4 to 4½ inches high for its entire depth of from 5 to 7 feet, as shown in Fig. 3 (*c*). The cutting of the coal is done by teeth inserted in a chain, which travels about a frame, as shown in Fig. 4. Timbering at the face hinders the operation of the chain machine, and may influence the depth of the undercut.

With a soft coal that breaks easily, the thin undercut, Fig. 3 (*c*), gives a larger proportion of lump coal; some coals, however, break in large masses and unless the front of the undercut is high, as in (*a*) and (*b*), the coal will not fall out, and extra labor is required to break and load it.

All cuttings made by a chain machine are slack, while those made by the pick machine are at least one-half lump and the remainder largely nut and pea, which usually have a greater market value and for which there is more demand.

COMPARATIVE MERITS OF DIFFERENT TYPES OF MACHINES

10. The pick machine is the best type for mining under unfavorable conditions, such as where there are rolls in the floor, boulders, pyrites in the form of thin layers or sulphur balls, clay seams, tender roof, and excessive roof pressure.

Whenever the chain breast machine is set to work on the floor line of the coal, it undercuts the coal in a straight line from the face of the coal to the full depth of the undercut. Should there be any change in the floor level or any hard rolls of clay, or balls of iron pyrites in the coal, the course of the chain cutter cannot be diverted so as to miss them, and its teeth will often be broken by the hard substances encountered. The surface of hard rolls is often covered with iron pyrites in thin layers, and the rolls contain *sulphur balls*, consisting mostly of iron pyrites, which are often harder than the teeth or bits used for cutting. The machine must then be stopped, withdrawn from the cut, the bits renewed, the machine reset, and the operation of cutting commenced again, with the possibility of a similar experience at any moment. With the pick machine, these obstructions can be avoided, the floor line can be followed in the case of hard rolls, and sulphur balls can be cut around. Wherever the roof pressure on the coal is excessive, a chain machine cannot be used successfully, as the undercut being but 4 to 4½ inches high, the coal may settle down on the machine and hold it fast so that it can neither advance nor withdraw, and it is necessary to dig out the machine; this does not occur with the pick machine. Also where the roof is tender and much timber is required near the face, the ordinary chain breast machine cannot be used, as it requires from 10 to 14 feet of clear space along the face of the coal the entire width of the room or entry. The pick machine, however, can be manipulated easily among timbers if they are systematically set, and not too numerous or too close to the face. For this reason, the pick machine is better suited to the work of drawing pillars than is the chain breast machine. Wherever favorable mining conditions exist, the chain breast machine can be used with economy. In long-wall work, the same conditions determine the choice between the pick machine and long-wall machines of the disk, chain, and cutter-bar types.

11. Type of Machine as Influenced by Method of Working.—In the pillar-and-stall method of working, a comparatively small face only is cut at one time, i. e., the width of a room or pillar; hence a machine for such work should be compact in form, not of too great weight, and one that can be moved with ease from place to place, easily set up for operation and taken down, and not requiring fine adjustment on the floor or bed in order to do its work. Both the pick machine and the chain breast machine have been successfully used in this method of working.

For long-wall work, the machine is required to cut continuously along the face of the coal. It should be compact in form and occupy as small a space as possible; it should be self-propelling, and capable of being worked on a jagged or a circular face of coal; and should be so arranged that in its progress along the face of the coal the cutting apparatus can be lowered or raised, so as to cut above or below obstructions that may present themselves in the path of the machine. This will also enable the machine to follow the floor line of the coal. The most successful long-wall machines are either those of the disk type, chain machines having an endless chain working around an arm placed at right angles with the bed of the machine, or the cutter-bar type of machine. The pick machine is also sometimes used in long-wall work.

POWER USED IN COAL CUTTING

ELECTRICITY

12. There are practically but two kinds of power for operating coal-cutting machines, *electricity* and *compressed air*. **Electricity,** being a very flexible form of power, has come into very general use and is the power most generally used in connection with chain machines. It has not, however, been successfully applied to coal-cutting machines of the pick, or puncher, type, and, moreover, its use in gaseous mines is not advisable on account of the sparks it often produces, which increase the danger of mine explosions.

In the maintenance of electric plants, skilled men are required, as numerous repairs calling for technical skill are likely to be necessary. The voltage for coal-mining machines should not exceed 500 volts, from 220 to 250 volts being often preferred on account of the danger to life from contact with the wires with higher voltages, and even 250 volts is dangerous to mules and to persons having any weakness of the heart.

The advisability of a central power plant for a number of mines depends on the number and location of mines that can be economically supplied from a given point. The larger the number of mines that can receive their power from one station, the less will be the cost of power per mine, and the cost per ton of coal mined. The distance to any one mine should not be too great, because the greater the distance the larger is the wire required to convey a given current and deliver it with the least practical drop, or loss, of pressure at the point where the machines are in operation. This matter should be closely investigated and determined before the plant is installed. The direct current is generally used for operating coal-cutting machinery.

13. Wiring for Coal-Cutting Machines.—The wiring of a mine for operating coal-cutting machines by electricity is no different from that required for haulage and pumping, as described in *Haulage*. The wires from which power is taken to operate machines should be kept extended, as far as practicable, to the face of the entries, and should at no time be farther from any working place than the length of the cable that is used to connect the machine with the power line, and which is carried on a reel from place to place with the machine. If possible, the wiring of the mine should be divided into sections and each section connected to a central point, where there is a switchboard arranged so that the sections can be supplied with power independently of each other. The reason for this is that a short circuit occurring in any one section may not cut off the power in the other sections. This is of extreme importance in mines of very tender roof, where falls are likely to occur, bringing down the wires with a resulting short circuit and loss of power.

It is often advisable that the line for transmitting power for machines and pumps should be separate and distinct from that used for haulage. This is not the usual practice, nor is it at all times advisable, but wherever so installed short circuits in the workings do not affect the haulage; and further, should the motor for haulage be overloaded in climbing a very steep grade, the resultant drop or loss of pressure in the line will not affect the machines at the far end of the mine.

COMPRESSED AIR

14. Air under pressure, when rightly used, is an economical means of transmitting power. Its advantages are numerous; used in gaseous mines it assists ventilation, and has been the means of saving life by supplying fresh air to imprisoned miners; its pressure can be so regulated that it will remain the same whatever the number of machines in operation; the speed of an air compressor is slow, reducing the liability to accidents that often occur in the use of high-speed machines; the repairs of compressed-air machinery do not require as expert mechanics as are required for electric machinery.

15. Transmitting Compressed Air.—Compressed air flows through pipe lines to the place where it is used. This flow is impeded by the friction of the air against the inner surface of the pipe, producing a drop in the pressure at the working end of the line. The proper size of pipes should therefore be used, this depending on the distance of transmission and the amount of work to be done. In a mining plant, high pressure is by far more economical than low pressure, because air can be conveyed in smaller pipes under a high pressure, and smaller cylinders can be used on the coal-cutting machines, reducing the cost of installation and repairs.

In laying a pipe line, the same rules should be applied as in wiring mines for electric power; i. e., the mine should be divided into sections, with properly placed valves to control the air. Under tender roof, the pipes should be laid on the floor of the mine to avoid their being broken by a fall. The pressure of the air used for mining machines is 75 to 80 pounds, while for haulage purposes a pressure of 600 to 700 pounds is used. Hence, it is generally impracticable to take the air needed for the mining machines from the air line used for haulage purposes, and a separate pipe line is laid into the face of the mine to supply air for the machines.

The power used for haulage purposes is too frequently made the governing element in choosing the power for cutting the coal. In many cases, electric chain machines have been installed for cutting the coal, simply because an electric haulage was desirable, although the mining conditions were adverse to the chain machine, and favored the compressed-air puncher machine. At a number of operations, both forms of power are used—electricity for haulage and compressed air for coal cutting. It must be borne in mind in choosing a suitable power that such conditions as ventilation and the support of the roof are entirely different along the passageways where the haulage is done and at the face where the coal is cut.

CLASSIFICATION OF COAL-CUTTING MACHINES

CHAIN COAL-CUTTING MACHINES

CHAIN UNDERCUTTING MACHINES

16. Fig. 4 shows the construction of the ordinary form of **Jeffrey chain machine.** It consists of an outside frame *a*, an inside, or cutter, frame *k*, and a motor *m*. The cutter frame is of cast steel and so proportioned as to present a compact and symmetrical triangular appearance. The outside frame consists of two steel channel bars and two angle bars firmly fastened together by means of heavy steel braces. A heavy steel casting *e* joins the channel bars at the front of the bed frame and forms the gib, or guide, for the inside frame; on this casting, also, the front jack *f* is mounted. At the rear end of the frame is a solid steel housing that carries the cross-bar for supporting the rear

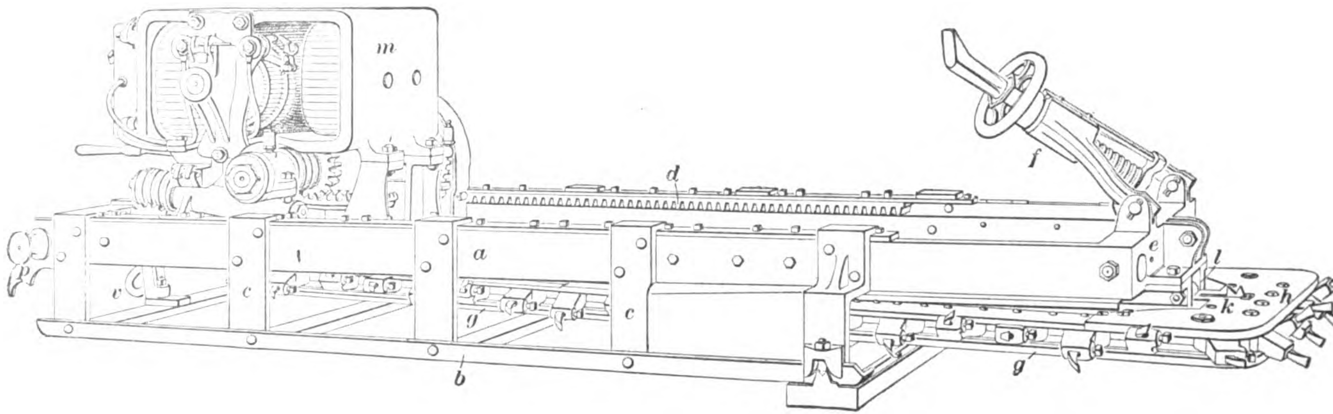


FIG. 4

jacks, or braces, to the roof. The inside, or cutter, frame *k* consists of a forged-steel center rail, a cutter head *h*, and two steel guides *l* in which the cutter frame runs. The cutter frame is advanced and withdrawn by power transmitted from the motor through worms and gearing to the feed-rack *d*. The feed-racks, made of rolled steel and having machine-cut involute teeth, are firmly bolted to the outside frame; these racks are made in sections for convenience in making repairs. Power is conveyed from the motor to the different parts of the machine, as required, by a system of gearing and worms.

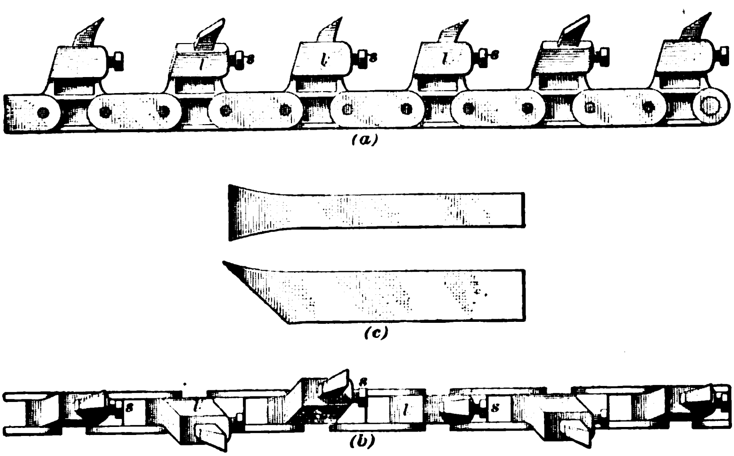


FIG. 5

The rear end of the outside frame is provided with hooks *p* for convenience in handling the machine. The cutter frame is so built that but three wheels are required—two idlers or sheaves in the base of the triangle, which is the front, and one driving sprocket at the apex in the rear; on these the cutting chain travels in its course about the sliding frame. This chain is driven by the rear sprocket in the apex of the frame.

17. Chain and Bits.—Fig. 5 (*a*) shows a top view and Fig. 5 (*b*) a side view of a portion of a cutter chain. The chain carrying the cutter is subjected to great stresses and wear and tear, and consequently must be made strong and of as few parts as possible. Since it is necessary to sharpen the cutters frequently, an easy means of detaching them is provided by having a socket in each alternate solid link *l* in the chain, into which the bit is fitted and held firmly in place by a setscrew *s* adjusted from the side of the link.

The number of bits on a chain varies according to the style of the machine, and the ideas of the manufacturer as to what the different structures of the coal require. The speed of the cutting chain also varies from 150 to 300 feet per minute in different machines and in different coals, the harder the coal the higher being the speed required.

The usual form of the bits, or cutters, is shown in Fig. 5 (*c*). These bits are made of good tool steel either by drop forging at the factory from which they are purchased, or by hand forging at the mine blacksmith shop; when dulled by use, they are sharpened and tempered by the mine blacksmith. When tempered properly, they should be blue in color, because if tempered to a straw color they will be too hard and brittle, and when a sulphur ball or other obstruction is encountered will break off close to the lug of the chain. Bits are usually set in the chain when the power is on the machine; this enables the chain to be brought to any desired position, which is quite necessary, as the chain is exposed for a part of its length only. After the bit is placed in the socket of the chain, it should be accurately gauged and the setscrew securely tightened. The life of the bit depends largely on the material it cuts. When cutting coal containing sulphur, bits do not last as long as when the coal is practically free from sulphur; in the latter case, as many as seventy-five cuts have been made without changing the bits; while with coal containing sulphur, especially sulphur balls, the bits often require to be changed three or four times in the cutting of one room. This shows that no estimate can be given on the life of a bit in cutting coal, as everything depends on the material it cuts, the handling of the machine, and the tempering of the bits.

18. The Motor.—The electric motor used on the machine described in Art. **16** is of the multipolar iron-clad type with the armature running horizontally and having its field coils thoroughly insulated and protected from injury. A compact starting switch or rheostat is arranged so that the motor may be run either forwards or backwards, as desired. The windings and conductors are so arranged and proportioned that a minimum rise in temperature takes place, and an overload can be easily carried without sparking at the commutator. The parts of the motor are shown in Fig. 6; *a*, *a'* are the bearings in which the armature journal runs;

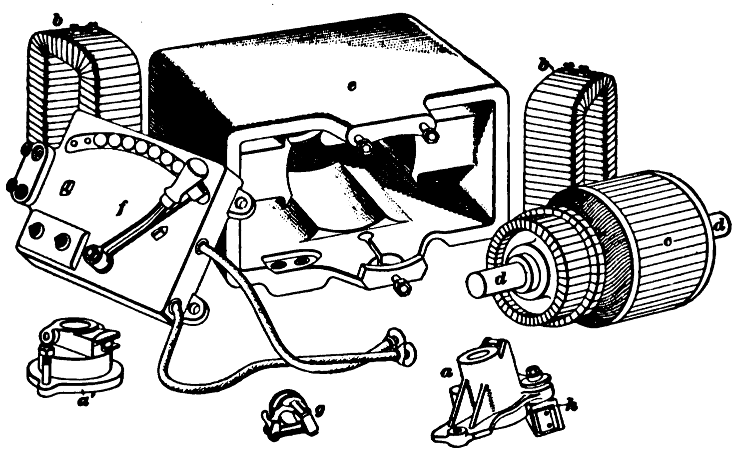


Fig. 6

b, the field coils; *c*, the armature; *d*, the journal of the armature; *e*, the iron-clad case; *f*, the starting box or rheostat; and *g*, the brush holder shown in place at *h*.

The motors on machines are usually protected by a dust-proof and waterproof casing, but any bearings that are necessarily exposed to the dust in the mine should be frequently cleaned and kept well oiled.

19. Compressed-air motors are also often used on chain machines. These motors are twin air engines built compact and strong and mounted on the machine, as shown in Fig. 7. Except in the motor, chain machines operated by compressed

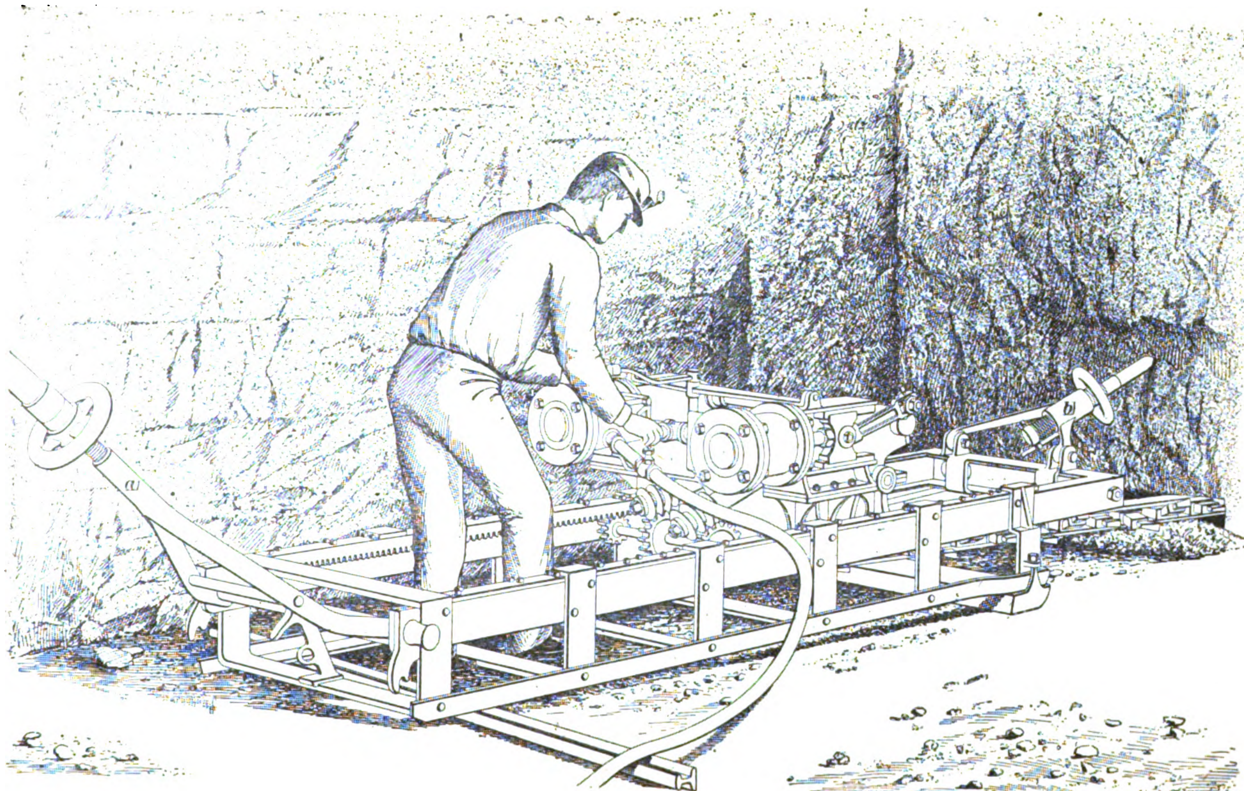


FIG. 7

air differ in no way in their construction and operation from similar machines operated by electricity.

20. Fig. 8 shows the "Heavy D" type of the **Morgan-Gardner machine** mounted on a truck for transportation. The cutting parts are the same in principle as the machine already described. The electric motor that furnishes the power is different and is of a multipolar iron-clad type with internal fields; the armature is a toothed Gramme-ring type,

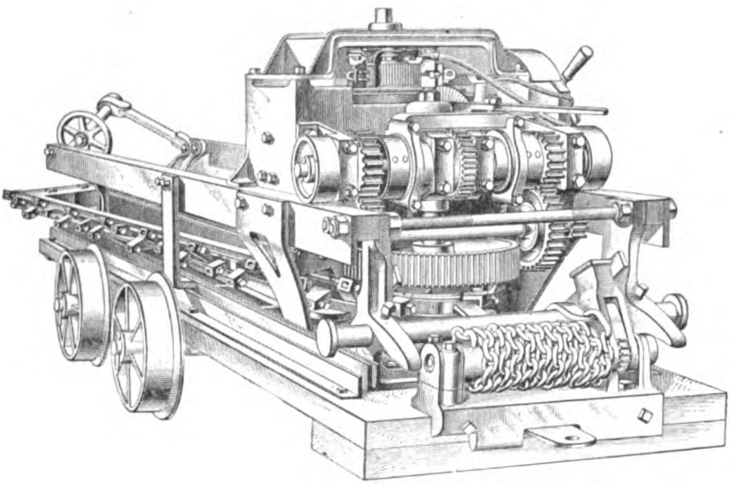


FIG. 8

with the coils wound in slots and below the face of the armature. This, as in the former machine, protects the coils from injury from rough usage or in case of accident. The field coils are wound on spools that slip over the pole pieces and can be easily removed. The armature is mounted in a vertical position. This form of mounting has an advantage in reducing the number of gears necessary to change the direction of the motion.

21. Fig. 9 shows the **Goodman machine**, which differs from those described in several points. It consists of a stationary frame *a* and a motor mounted on a frame *b* sliding on guides *c* attached to the stationary frame. The motor is

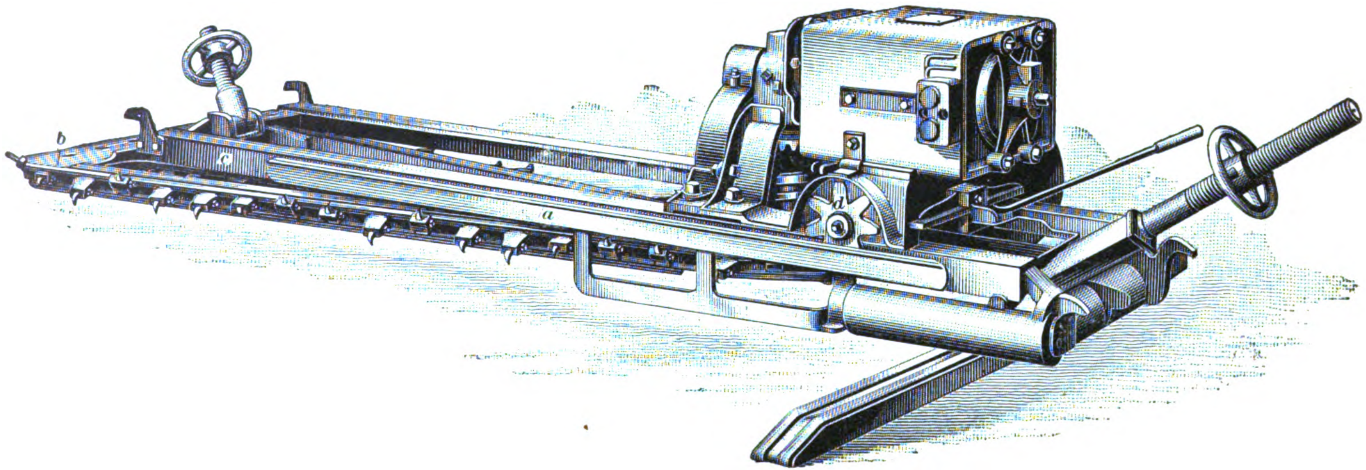


FIG. 9

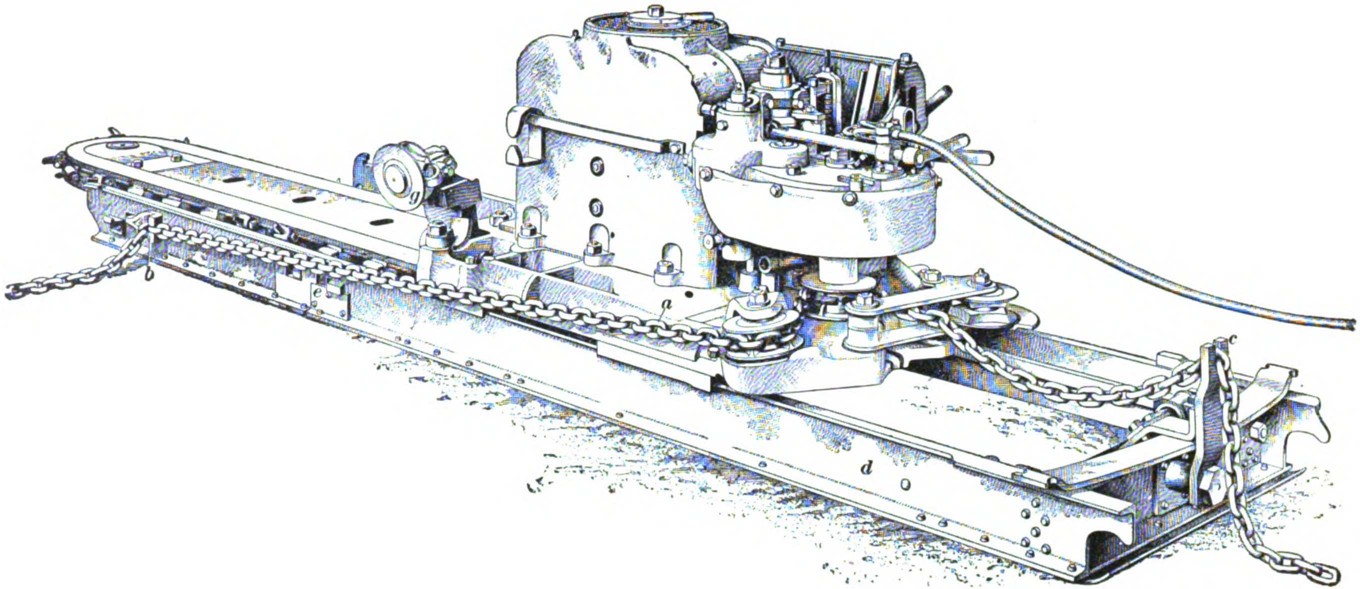


FIG. 10

driven either backwards or forwards by the sprockets *d* at its sides.

The sliding, or traveling, frame is supported entirely under the stationary frame, which enables the machine to cut very close to the bottom when it is desired. It can also be adjusted to cut higher, if required. The motor used with this machine is compound-wound, which causes it to automatically adjust its speed to the resistance offered to cutting; thus it slows down with hard cutting or dull bits.

22. The **Sullivan electric chain machine,** shown in Figs. 10 and 11, differs in a number of particulars from those already described. The frame that carries the cutter chain is fed forwards in making the first, or "tight," cut by a driving sprocket working on a feed-chain *a*, Fig. 10, the end *b* being made fast to the front end of the machine frame, and the other end being held in the slot *c* at the back of the machine. When the first cut is completed and the machine run forwards to the front of the frame, the back part of the frame, or pan, *d* is detached at the point *e*; the end of the feed-chain is then carried through the block at *g*, Fig. 11, shown also raised out of the way in Fig. 10, and anchored in the opposite corner of the room. The other end is held by the ratchet shown at *f*, Fig. 11, by which the tension on the chain can be regulated. The machine then makes a cut sidewise clear across the breast without stopping. The advantages claimed are the saving of time by making one set-up suffice for the whole room and considerable flexibility in following an uneven bottom by elevating or depressing the feed-chain. A perfectly smooth bottom is left, while the debris need be thrown back only a short distance.

The machine shown in Fig. 10 is the latest type of the Sullivan machine; that shown in part in Fig. 11 is an earlier form. The two machines are the same in principle and method of operation, the difference being principally in the cutting end.

23. The **cutter chain** shown in Fig. 12 (*a*) is of the newest type, used in the Sullivan machine shown in

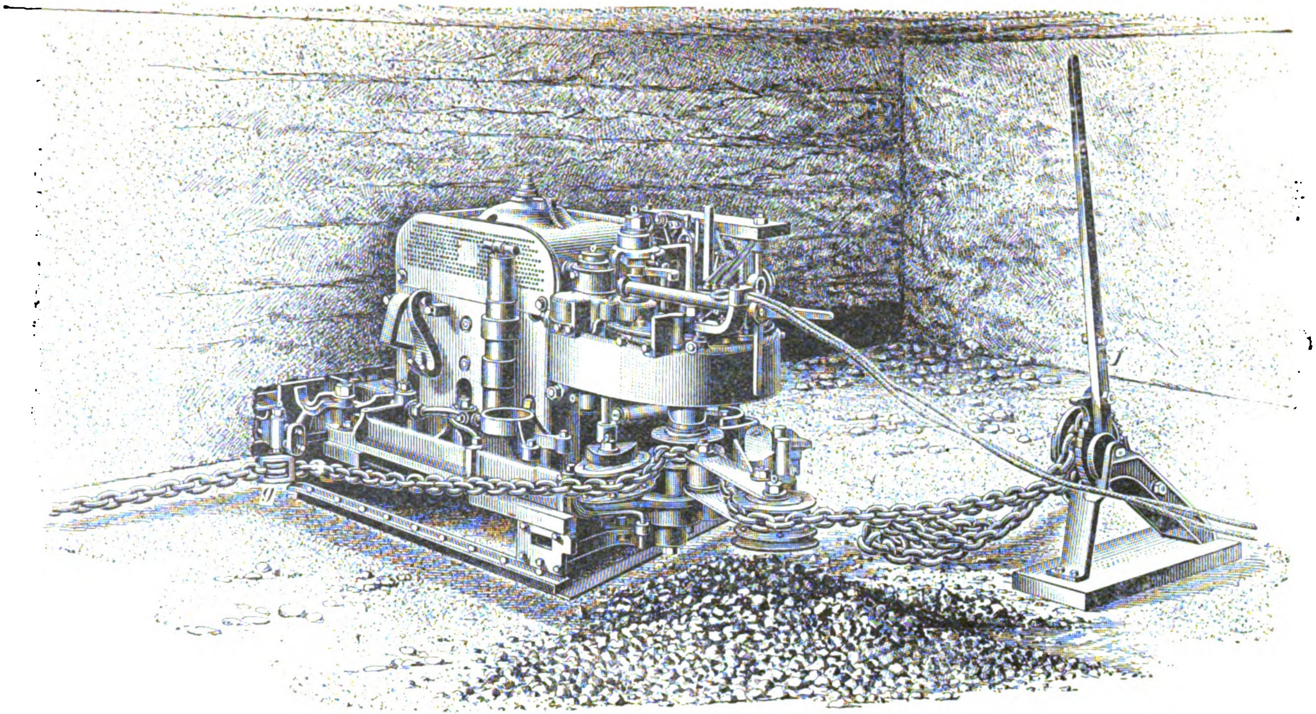
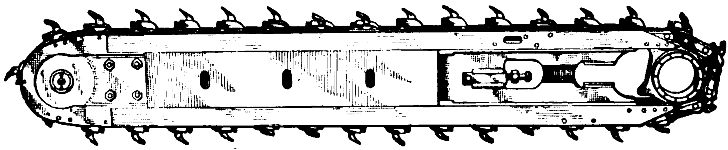
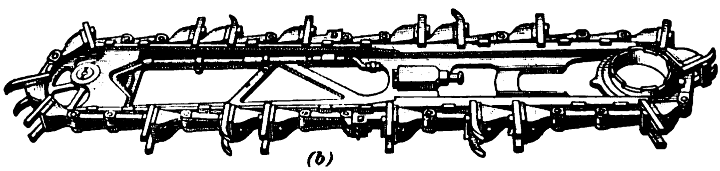


FIG. 11

Fig. 10. It is of the link-and-strap pattern and runs in close-gibbed guides. The steel cutters have seven positions and the coal is therefore cut, not broken, out. This is claimed to be an improvement over the form of cutter shown in Fig. 12 (*b*), which was formerly used, in which the cutters were set opposite each other in pairs and the core, or center between the teeth, broken out by rakers.



(*a*)



(*b*)

Fig. 12

24. A new type of machine invented by Mr. Leiter, the original inventor of the chain breast machine, has the following principal differences from the ordinary chain breast machine, viz.: The chain has lugs with two holes for the bits, one above the other; this allows the bit to be placed far in the socket, and as a good hold is thus secured the gauging of the bit is unnecessary. Another feature is a special form of bar-iron about 1 inch in thickness attached to the fore end of the sliding frame of the machine. This iron is triangular in form, with the base of the triangle resting on the rib of the coal as the machine advances. The angle at the apex of this triangle is about 15°. The purpose of this triangular form is to keep a chain machine from working toward the right; for example, as the teeth take hold in cutting the coal, the machine is continually drawn toward the right, causing the teeth to cut deeper and deeper into the coal. This triangular form prevents this from being done. Further, the strain is taken off the machine, and the work of the jacks

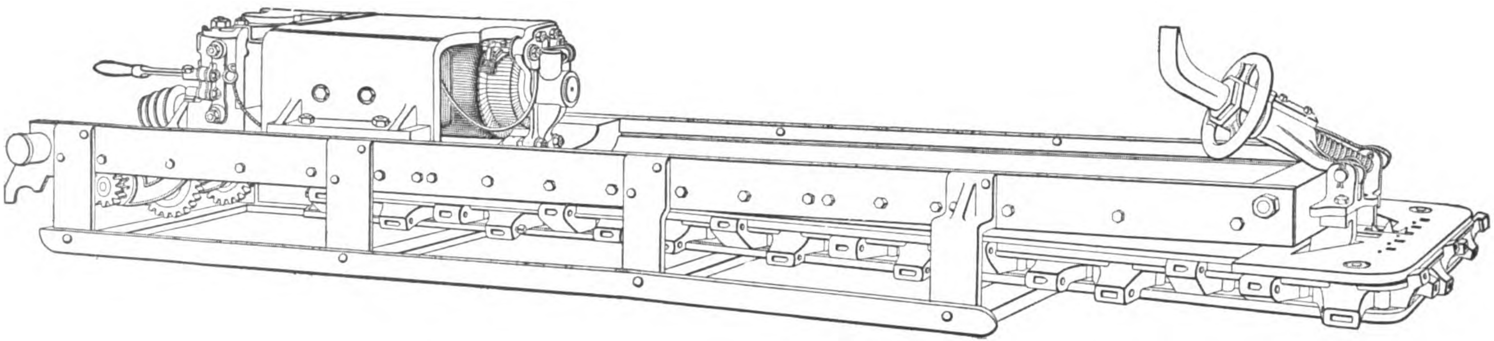


FIG. 18

on the machine is not so important as when this device is not attached.

25. Machines for Thin Veins.—In addition to the styles of machines used for medium or thick veins, most manufacturers build smaller and more compact machines especially adapted for use in low seams. Fig. 13 shows their general construction, which is similar to the ordinary types.

26. Reel and Cable.—In order to avoid the expense of wiring each room in which the coal is cut by machine, a cable is used to transmit the power from the feed-wire in the entry to the machine in the room. This cable and the reel on which it is wound, Fig. 14, are carried from place to place

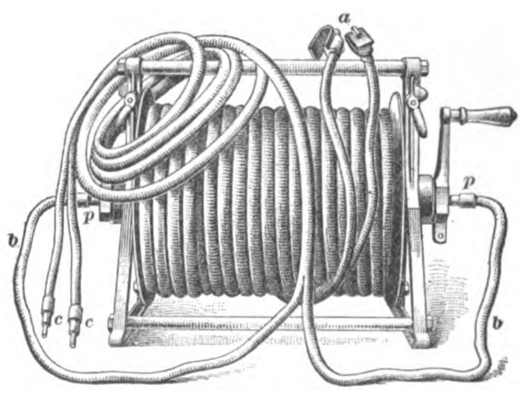


FIG. 14

in the mine on the mining machine. The length of the cable varies from 150 to 300 feet, depending on the length of the rooms. It is of a twin type, being composed of two wires, or conductors, thoroughly insulated from each other and securely bound together. On one end of each conductor of the cable are hooks *a*, as shown in Fig. 14.

When the machine is to be taken into a room, the cable is attached by these hooks, or clamps, to the feed-wires in the entry, one to a positive and the other to a negative wire, at the mouth of the room, and the cable unreeled as the machine advances toward the face of the room. The two conductors forming the cable are permanently attached at the other end to the two ends of the axle of the reel; this axle is so arranged that its metal ends are insulated from each other. A short cable *b* is used to connect the machine with the respective ends of the axle of the reel by inserting the plugs *p*, *p* at the end of each conductor into the holes in the ends of the axle. The plugs *c*, *c* at the other end of this cable are then inserted in the poles of the machine and the connection is complete.

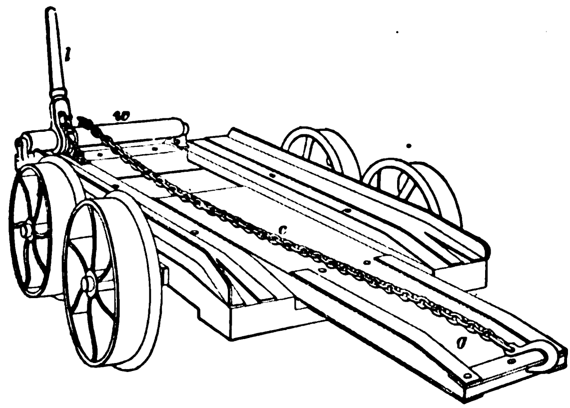


Fig. 15

27. Trucks.—The cutting machine is carried about the mine on a four-wheeled truck, Fig. 15, of the same gauge as the mine car. On the back end of this truck, where the motor attached to the machine rests, is a ratchet and reel *w*, to which a chain *c* is attached, by which, when the machine is to be loaded, it is drawn from the floor of the mine on to the truck. The truck is built to perform the part of a skid, the front end *g* of the truck resting on the floor of the mine when the machine is being loaded.

28. As the machines are heavy, the loaded trucks are difficult to push by hand up and down steep grades. To overcome this in a mine equipped for electric haulage, **power trucks** are sometimes used, the motor that operates the machine being mechanically connected with the running gear of its truck. This connection is accomplished in various ways by different manufacturers, but it usually consists of an endless chain running over sprocket wheels, one of which is attached to a journal on the motor and the other to the axle of the truck; or the motor and journal may be connected with a journal on the truck by a sprocket chain or by gearing and this journal, in turn, similarly connected with the axle of the truck. A common arrangement of the first kind is shown in Fig. 16. The motor is so designed as to be readily disconnected from the coal-cutting machine and is equipped with a reversing switch so as to run either forwards or backwards. This arrangement has effected great economy in transferring machines from one room to another.

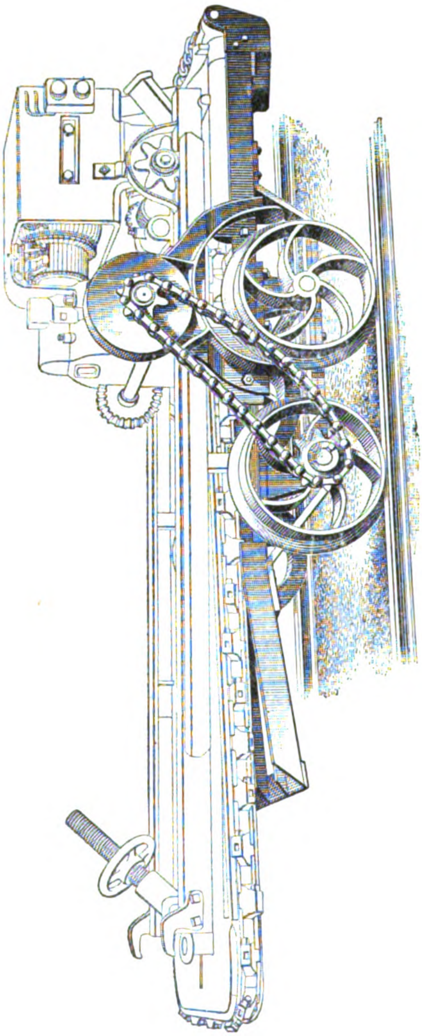


Fig. 16

29. Depth of Cut, Power, and Weight. The chain breast machine makes a cut of from 5 to 7 feet in depth, 39 to 44 inches in width, with a height of 4 to 4½ inches, and develops about 8 horsepower when cutting under a full load. The average-sized machine weighs from 2,400 to 3,000 pounds. The type of machine used in low veins weighs from 1,500 to 2,000 pounds.

30. Capacity.—The amount of undercutting that a machine can do in a given time depends on the men running it, the character of the coal, and the presence of faults and impurities and other obstructions and hindrances to the work of cutting. Under favorable conditions, one machine operated by two men is recorded as having made 104 cuts, each 6 feet deep, in 10 hours, these cuts being made in rooms and entries. This is exceptional cutting and much higher than the average. It is fair to say that a machine making from 36 to 45 cuts, 6 feet deep, in 10 hours, is doing good work. An average of 40 cuts, 42 inches wide, will represent 140 lineal feet of face, which for coal 6 feet in height will make approximately 140 tons of coal per shift of 10 hours. Under unfavorable conditions, the result will not run nearly so high. There are cases where, with the chain breast machine, the undercutting of one room per shift of 10 hours is considered good work. The capacity of the machine or the number of runs it will make differs in every locality and seam, and experience in the use of machines in a given locality is by far the best guide when the capacity of the machine is to be considered. The time it takes for a machine to make a cut is generally but a small part of the total time consumed in its operation, unless unfavorable conditions exist, as the time for moving and resetting the machines greatly exceeds the time of cutting. In cutting clean coal, a machine should make a cut its full depth in 4½ minutes, and 1 minute more will be required to withdraw the machine; the rest of the time is consumed in loading and unloading, moving and setting the machine in place ready for another cut, besides such delays as waiting to have rooms cleaned for operation, waiting for driver, and many small accidents that are liable to occur at any time.

CHAIN SHEARING MACHINE

31. The **chain shearing machine**, Fig. 17, is essentially the same as the ordinary chain undercutter, except that it is mounted on its edge on a truck and provided with gear mechanism for raising it when necessary. This mechanism is driven by the motor, and consists of the spur gears *a* at the rear of the machine and a rod that runs from these gears back to the column *p*, which is provided with coarse threads. On the end of this rod, there is a worm that engages a worm-wheel screwed on the column *p*. When it is desired to raise or lower the machine, this set of gears is made to turn the rod and worm-wheel by throwing in the friction clutch *f* by means of the lever *l*. As the worm-wheel is turned in the proper direction to raise the machine, it presses against a shoulder, or cup, so pivoted that the machine may slightly turn on a longitudinal axis without detriment to any part of the hoisting device. The machine is further steadied by the columns *n* on opposite sides and the rear jacks *r*. It will be noticed that the truck is rigidly attached to the machine. Before making a shearing in an entry, for instance, the road can be temporarily shoved to one side, whereby the machine can be run directly to the proper place to commence work.

32. Another type of shearing machine, Fig. 18, is supported on four columns or jacks and is provided with mechanism for raising and lowering it. The construction is quite similar to the chain cutter mining machine. There is a bed frame, sliding chain cutter frame, and a motor carriage. The bed frame consists of two rectangular steel channel bars and two steel angle bars firmly fastened together by means of heavy cast-steel braces. A heavy steel casting joins the channel bars at the front end of the bed frame and forms the jib or guide for the cutter frame. At the front extremity of the channel bars, two lugs are riveted for supporting the split clamp for the front jack. The supports for the main jacks are located between the center and the rear of the bed frame, and the bearings for the truck wheels are

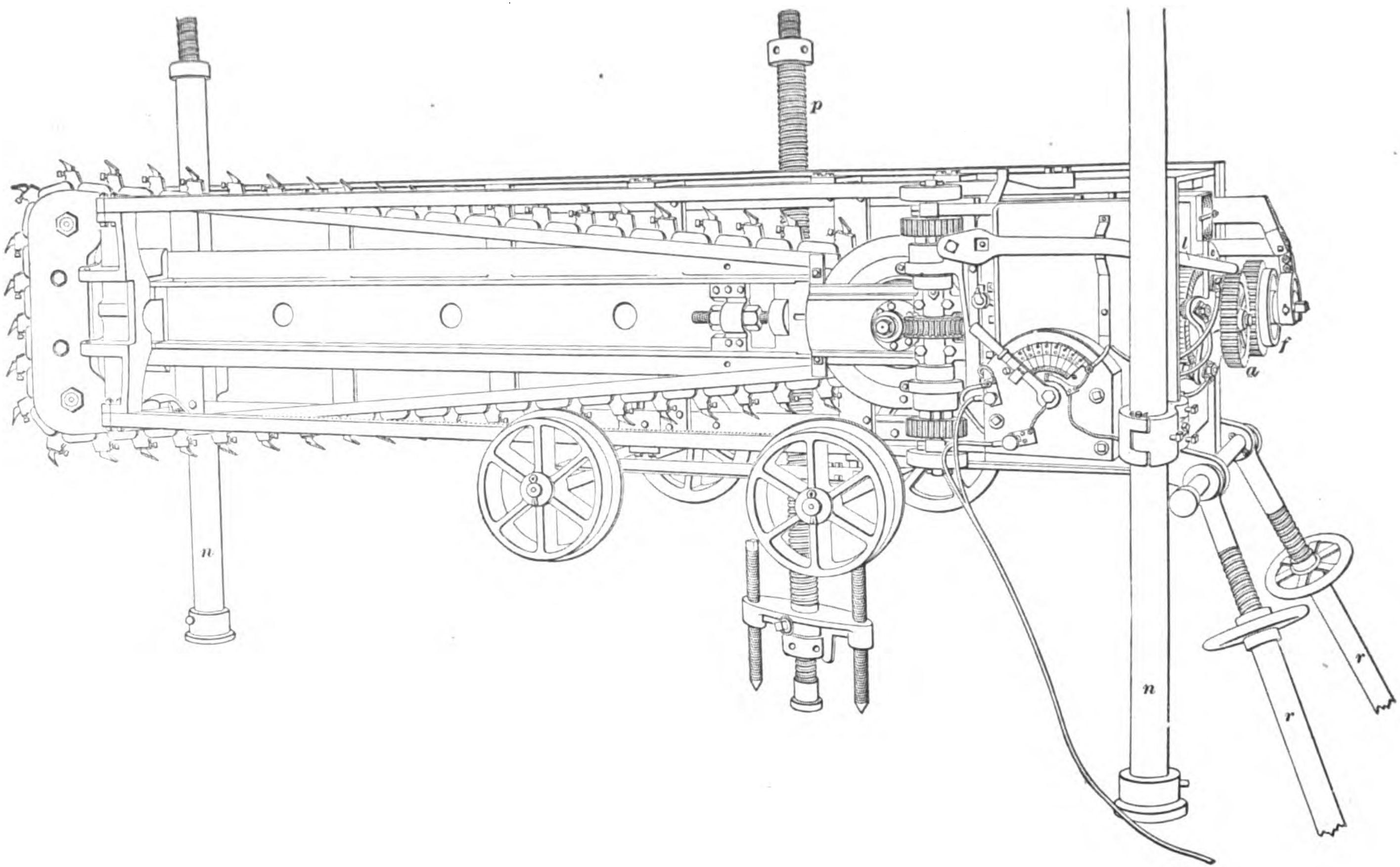


FIG. 17

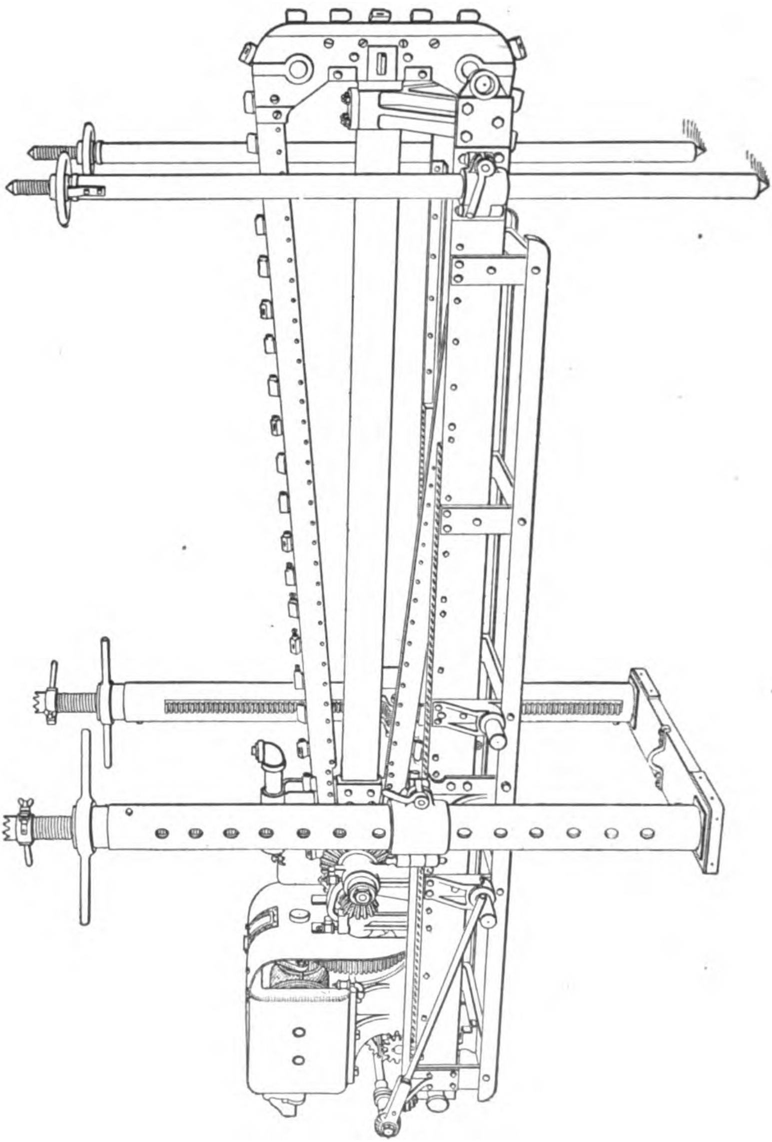


Fig. 18

placed on each side of these supports. The cutter frame consists of a steel center rail, a cutter head, and two steel guides in which the cutter chain runs.

33. Capacity of Chain Shearing Machine.—After these machines are properly placed and raised to position, the action and operation is practically the same as that of the chain breast machine. The chain shearing machine makes a cut 7 feet deep, 3 feet high, and 4 inches wide. In shearing coal by this machine, the amount of work performed depends more on the height of the seam than when undercutting, on account of the number of times it is required to move the machine and the time consumed in setting and adjusting the columns and jacks. A greater amount of time being thus lost, this machine cannot shear as rapidly as another chain machine can undercut. A fair average day's work for one machine shearing coal 6 feet deep, in a seam 6 feet high, would be from eight to ten places per day. This will vary, however, depending, as before, on the handling of the machine, the character of the coal, and the impurities contained in it, as well as the minor delays and accidents.

LONG-WALL MACHINES

DISK MACHINES

34. In the **Jeffrey electric long-wall machine,** Fig. 19, the cutting is done by means of bits or cutters inserted in the periphery of a cutter wheel, or disk, *a*. This wheel is made in different sizes to undercut from 3 to 6 feet deep and swings on its bearings in such a manner as to be adjustable in a horizontal plane. The machine travels along the face on a single rail *b*, which is held in position by being jacked to the floor by means of the column *c*, *c*. The height of these columns is adjustable by screws worked by the wheels *d*. The bottoms of the columns rest on the iron clamps *e* attached to the rail on which the machine runs, and they thus hold the rail in place, at the same time allowing the columns

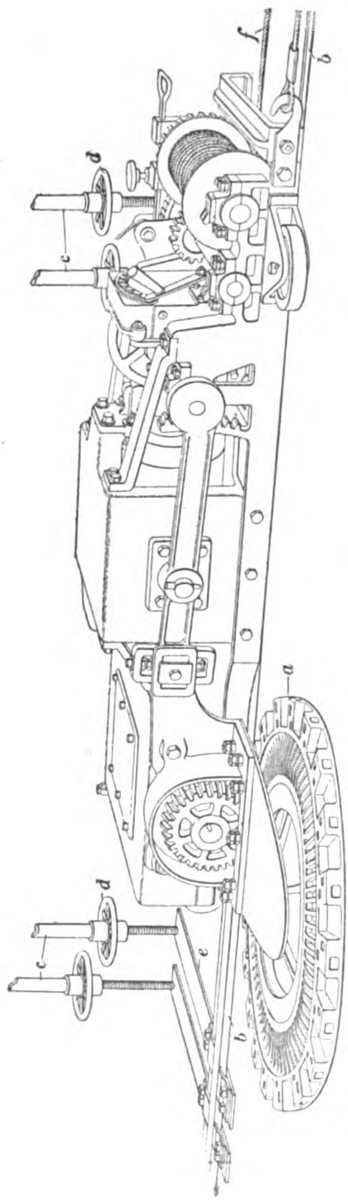
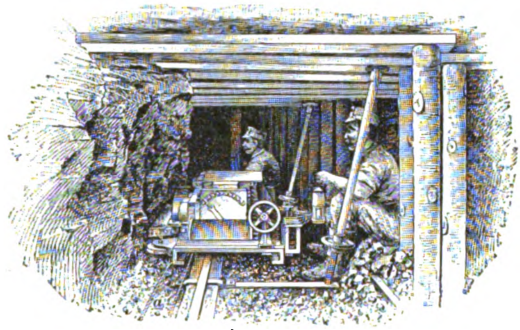


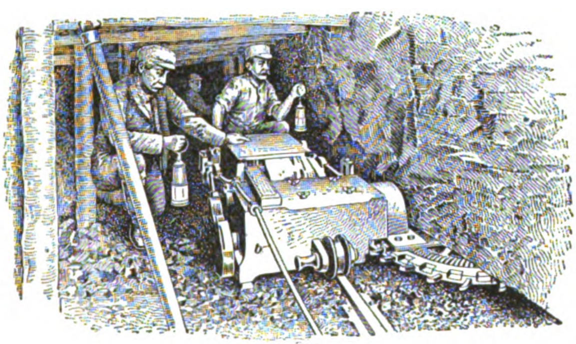
FIG. 19

to be set up a sufficient distance to one side of the rail not to interfere with the passage of the machine. The coal cutter is propelled along the track by means of a rope *f*, one end of which is fastened to the forward end of the machine and the other, after passing over a block fastened to a post some distance ahead, is carried back to a reel on the machine. This reel is operated by the motor, the speed being adjustable while the machine is in operation. The usual speed of travel of the machine is from 8 to 25 inches per minute. The method of operating a long-wall machine at the face is shown in Fig. 20. In Fig. 20 (*a*), the machine is moving toward the front drawn by the rope *a*. Fig. 20 (*b*) shows the machine moving in the opposite direction; *b* is the electric cable through which the power is transmitted to the motor.

35. The **Jeffrey compressed-air long-wall coal-mining machine** of the disk type is shown in Fig. 21. The cutting disks are made in various sizes, corresponding to depths of undercut of 3, 4, and 5 feet. The type of machine shown has twin engines, and is 22 inches high, 3 feet wide from face of coal, and about 8 feet long. The cutting disk is driven by the face pinion *b* shown at the left of the machine in the protecting hood. This pinion is on the main shaft, which is perpendicular to the face of the coal. On this shaft are also a spur gear driven by the crank-shaft pinion, and an eccentric,



(a)



(b)

FIG. 20

not visible in this illustration, that operates the ratchet for revolving the drum *c* on which the cable *d* is wound. The machine is provided with adjustable flanged rollers *e* at each end by means of which it can be raised, lowered, or tilted to conform to uneven floors and the variable conditions met with in cutting. These rollers run on a single rail provided with special ties and light jack-screws to take the side thrust due

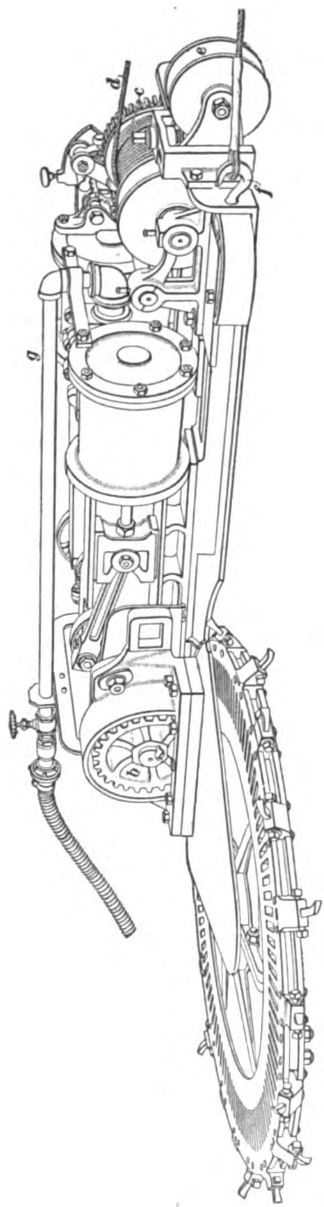


FIG. 21

to cutting. The rail sections, ties, and jacks are designed to be loosened, moved, and set with the least possible effort and loss of time as the machine advances along the face of the coal. The steel cable *d* passes from the drum *c* around a grooved pulley fastened to a jacking post in advance of the machine, and then back to the hook *f*, as shown. The ratchet is provided with an adjustable mechanism by means of which one, two, or three teeth are taken up at a time, thus varying the speed of feed. If necessary at any time to stop the feed without stopping the cutting disk, it is accomplished by the same mechanism.

As shown, the machine is in a position to advance toward the right. That part of the cutting disk nearest the observer rotates from left to right. When advancing toward the left, the cable is carried from drum *c* under guide rollers beneath the machine and around a grooved pulley fastened to a jacking post and is then attached to the machine frame at the left end; the cutting tools are reversed in their holders and the engines are reversed, causing the cutting disk to rotate in the opposite direction.

The machine parts are protected from falling pieces of roof by a large sheet-iron cover hinged on the air-supply pipe *g*.

CUTTER-BAR MACHINES

36. **The Lee long-wall machine,** Fig. 22, is a compact self-propelling machine worked with ease along a jagged or circular face and over an uneven floor, as the cutting arm *a* can be raised or lowered as desired. The track on which the machine runs consists of two rails *b c* made of angle iron tied together so as to make a solid track; the rail *b* nearer the face of the coal is notched and the other plain. The machine is propelled by means of a suitable toothed wheel *d* meshing with the notches of the notched rail. The cutter bar *a* is a shaft 2¼ inches in diameter at the machine and 1½ inches at the other end, placed at right angles to the machine and rotated by the motor as the machine proceeds along the track. On this shaft is wound a spiral band containing forty-two projecting teeth, so set that one-fourth of the teeth are cutting and three-fourths breaking the coal as the machine advances. The height of the cut with this machine is about 4 inches, and the cuttings are part slack and part nut.

CHAIN MACHINES

37. The **Goodman** type of long-wall machine, Fig. 23, consists of a steel frame about 7 feet in length and 32 inches in width. The side *a*, which is finished smooth, slides along the face of the coal, and the bottom is supported on steel shoes. In the middle of this frame is an electric motor, whose armature shaft extends lengthwise of the machine and is geared at one end to a sprocket that drives the cutter chain *b* around a steel cutter arm *c* extending at right angles to the frame. Three lengths of cutter arms are furnished with this machine to undercut the coal 38, 44, or 50 inches, as desired. The narrow cutter arm is carried on a swinging frame, and by means of a lever can be tilted in its width, up or down from the horizontal plane to enable the chain to cut over or under

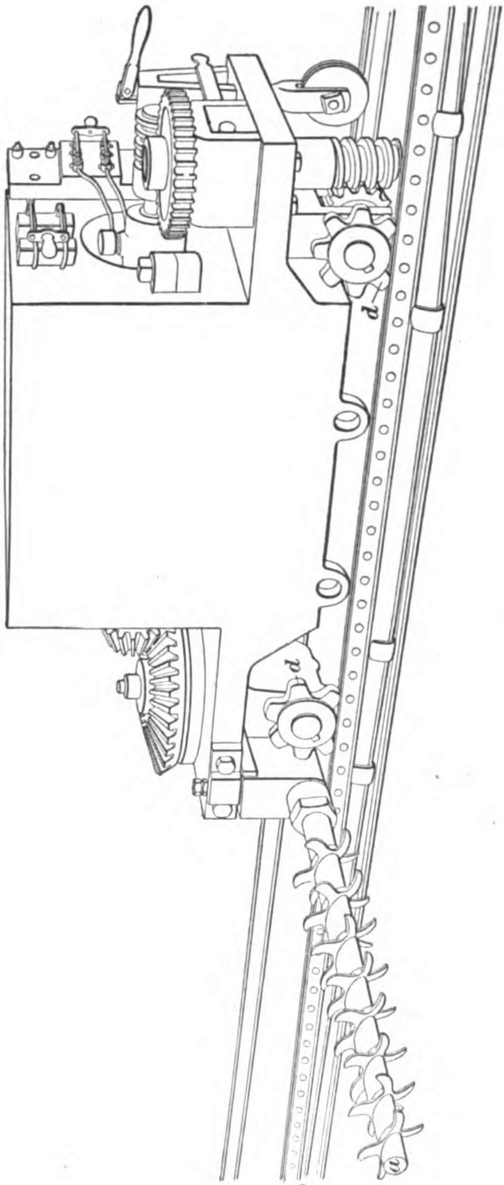


FIG. 22

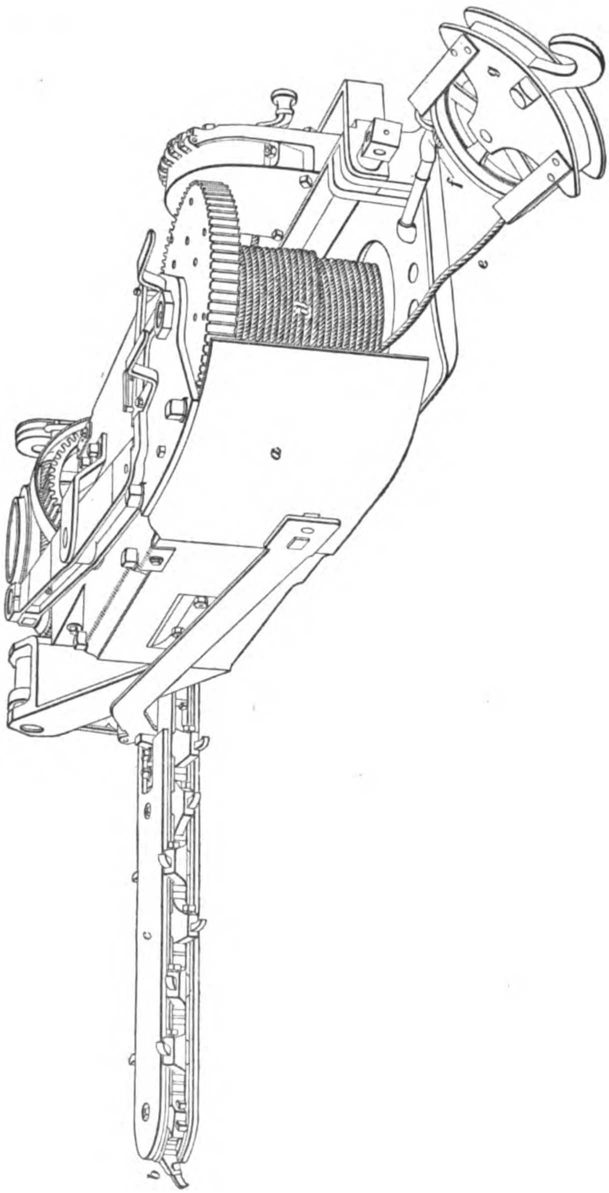


FIG. 23

any hard obstruction that may be encountered in the coal. A cable-winding drum *d*, at the other end of the machine from the cutter arm, is operated from the motor, by a ratchet lever and cam attached to the shaft of the driving sprocket. This drum winds up a wire cable *e*, one end of which is attached to the end of the frame of the machine at *f* after passing around a sheave *g* fastened to a jack some distance ahead. By this means, the machine is propelled along the face. In starting to undercut, a small jack-screw placed against the side of the machine at the cutter-arm end, forces the cutter arm under the coal, where it is retained by the action of the bits. No rails are necessary to keep this machine in position and it can be handled when the timbers are 3 feet from the face.

A special form of this machine, differing principally in being somewhat shorter, broader, and lighter, is also built for use where the room-and-pillar system is employed and timber set close to the face. This form of machine can be operated when timbers are as close as 5 feet from the face.

38. For working the block system in long-wall mining where parallel headings give from 200 to 400 feet of face, a reversible long-wall machine is made. This machine, in design, is exactly the same as that shown in Fig. 23, except that it has an extended frame on the cutter-arm end on which are rollers. When the face has been cut across, the sheave is anchored in the opposite end of the room and the feeding cable carried around the machine, over the rollers, through the sheave, and back to the machine in the usual manner. Then, by reversing the motor, the machine is fed backwards making the cut in the opposite direction from the first one. The extended frame serves to hold the machine in position.

In the use of this machine, a truck is rarely needed except when the machine is taken from one section to another. The machine undercuts from 3 to 5 feet deep.

39. The **Morgan-Gardner long-wall machine,** Fig. 24, consists of a cutter arm *a* about which a chain travels, the cutter arm being located at right angles to the main body of the machine. The cutter arm is swung by

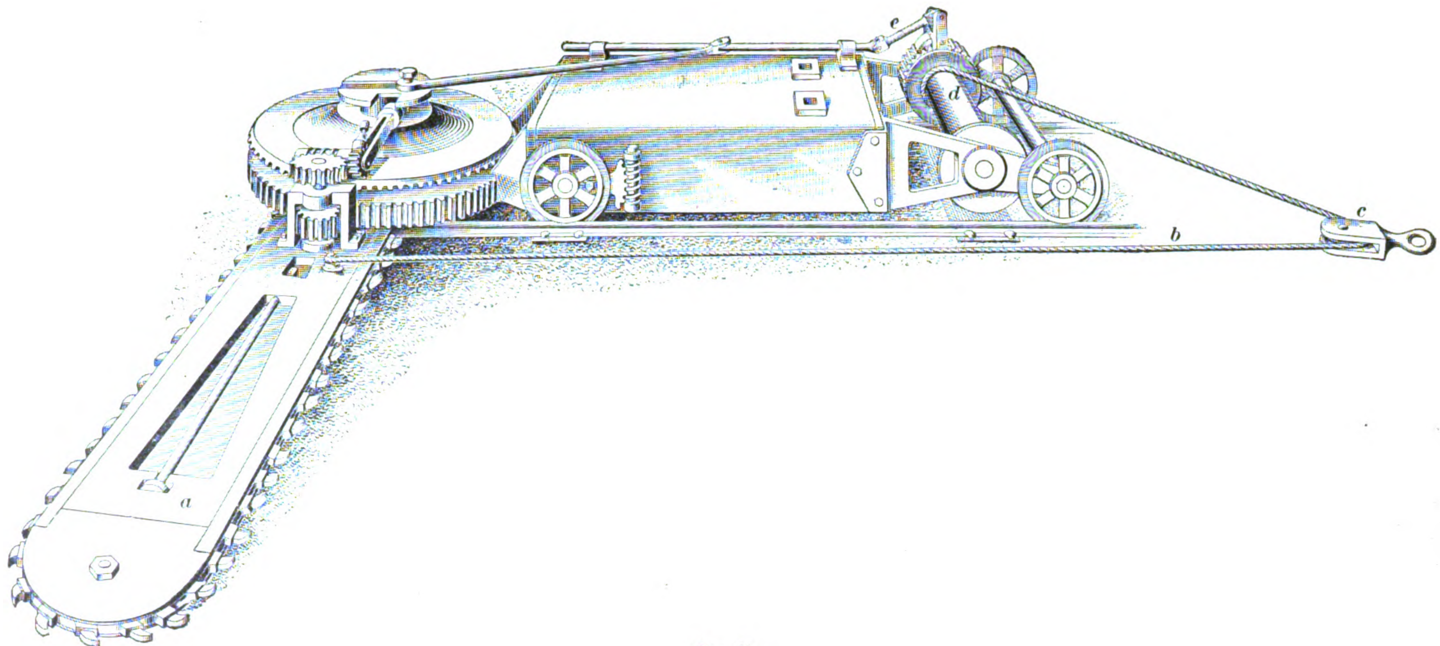


FIG 24

means of a cable *b*, running through a sheave *c*, to a reel *d* operated by the device shown at *e*, which connects it with the motor; by this same arrangement, the machine is fed forwards automatically along the face. This machine, in principle, is not much different from the one just described, except that it moves along the face of the coal on a track instead of on the floor of the coal; the device for operating the cable-winding arrangement is peculiar to this machine. It can be operated where props are from 3 to 4 feet from the face, weighs about 3,000 pounds, and undercuts from 2 to 6 feet in depth.

40. The **Sullivan long-wall machine** differs but little from the machine shown in Fig. 10, the principal difference being that the cutter arm is placed at right angles to the machine, and is so arranged that it may be swung in line with the machine, for convenience in loading on a truck, or to change the bits. The machine slides on a steel shoe and is fed along the face in the same manner as described for the machine shown in Fig. 10.

41. Capacity of Long-Wall Machines.—In the use of long-wall machines, a record has been made of 500 lineal feet of coal, cut 6 feet deep, in 10 hours. This is an unusual record, as a long-wall machine under ordinary conditions will not average more than 400 lineal feet. In a seam 4 feet thick, a length of 400 feet, cut 6 feet deep, makes approximately 280 tons of coal, which would be the average output of a machine per shift of 10 hours; but under unfavorable conditions the output will, of course, be much less.

HANDLING AND OPERATING CHAIN MACHINES

42. Getting the Machine to the Mine.—Skill and care are needed in moving a chain coal-cutting machine from the railroad cars to the working face in the mine. To accomplish the work quickly, with the least effort, and to avoid accidents to the machine, proceed as follows: Suppose the machine to be in the corner of the car with the cutter frame toward the doors; the runner takes a short bar hold in front, raising the machine enough to allow a helper to place a roller under the front end, in a diagonal position, so that the machine will travel sidewise to the center of the car. The runner and helper now both get short bar holds, not in the rear of the machine, which seems commonly to be the first impulse, but as near as possible to the end toward the direction in which it is desired to move the machine; they now throw the machine forwards and toward the center of the car. Here, by using a roller as a pivot and placing the bars on the side toward which the machine is to be moved, it is easily turned out of either door as desired. In handling the machine, from 1 to 5 minutes will be saved by placing the roller as described and throwing the machine forwards and sidewise at the same time. The machine truck having been unloaded and placed on the nearest mine track, the machine is hauled there and loaded on the truck to be taken into the mine.

43. Loading Machine on Truck.—The runner raises the windlass end of the truck and pushes it forwards until its front end is under the motor end of the machine, keeping the truck on a straight line with the side bars of the machine. The helper now attaches the truck chain, which he has unwound from the windlass, to the rear cross-rod of the mining machine, and the runner, by operating the lever of the windlass, drags the machine on to the truck, while the helper, with bar in hand, prevents any binding by steering the machine on a straight course. The reel, skids, bars, tools, etc. are then placed on the machine and transported to the next point where the machine is to be used.

44. Setting Bits.—The bits should be set and the machine tested under current before it is taken into the mine. Setting the bits is a very important part of the operation of a chain machine; much time can be saved if the helper starts on the left side of the machine and inserts the bits around in the chain, while the runner follows with gauge and wrench to set and tighten them. When the helper has filled all the exposed part of the chain, he gives the spanner a few strokes, which carry the bits already set by the runner back under the motor and bring the empty lugs out at the other side; he fills these, and then with a wrench helps the runner to finish by tightening the bits as they are gauged. All the bits or cutters should be set absolutely to gauge. The importance of this can be seen when it is explained that one cutter protruding farther than the others working in the same plane will do practically all of the cutting in this plane. This causes an undue jar and strain on the parts of the chain supporting this cutter, because it is doing the work that would be distributed among a number of cutters if all were set evenly to the same gauge. Particular care should also be taken to screw the setscrews down tight on the cutters to avoid their shaking loose and getting lost. Carelessness in this respect may cause unnecessary breakage and loss. The *whip* of a running flexible chain has a tendency to jar and loosen every part of the machine.

45. Testing.—With each machine is furnished a reel containing from 100 to 300 feet of double waterproof cable. On either end of the axle of the reel are holes for receiving the plugs of a short piece of double cable, as shown in Fig. 14, which connects the reel with the mining machine. The machine runner steadies the reel, while the helper, taking hold of the ends of the long cable, runs to the feed-wire on the entry, unwinding the cable from the reel as he goes; here he connects the terminals with the two feed-wires. When the reel ceases unwinding, the runner connects the machine by means of the short piece of cable. The runner should be careful to glance at the switch handle of the starting box before inserting a second plug in the reel to be sure it is on the off-position.

After oiling the machine, the brushes of the motor are examined to see that they have a good contact with the commutator. Any chips or dirt that may have lodged on or about the commutator should be removed, especially nails or chips of steel, which might cause considerable damage if unnoticed. Before starting, the runner should examine the chain and satisfy himself that the cutters will clear all around. He then takes a position behind the motor, with his helper on the left side of the machine, toward the front, and, with his right hand on the starting-box switch and his left hand on the machine feed-lever, he slowly turns the switch over until the machine starts, and if everything moves nicely, he throws the switch on full. The switch should never be left in any other position than "full off" or "full on." It is well to allow the machine to run several minutes in this way, and then, by blocking up the front of the truck, the runner can throw in the machine lever and run the machine out a foot or two and return it again by way of practice. This test of a new machine is not a waste of time, as it will not only reveal any injury that may have been received while the machine was in transit, but also give the men who are to operate it a good daylight view of its working.

46. Taking the Machine Into the Mine.—At a slope or drift mine, the machine, loaded on its truck, is hauled into the mine as any mine car; but at a shaft mine it must be lowered on the cage, or in case the cage is too short to hold it, the machine should be swung below the cage and carefully lowered, end down, into the mine. This operation requires great care.

Two strong log chains should be used for swinging the machine below the cage. There should be at least three men on top and three below, each with a crowbar, to receive the machine at the landing. The cage is raised above the landing and three or more stout timbers placed across the shaft; these should be long enough to overlap well on each side of the shaft, and at least 6 feet on the side from which the machine is received. From the truck, the machine is unloaded on to the timbers, and, using small rollers not more than 2 inches in diameter, is run forwards until the motor is directly under the center of the cage, with the cutter end extending in the direction the machine is to take on the roadway when it reaches the bottom of the shaft. This is important, because, when the machine reaches the bottom and is pulled out on the track, it will assume the proper position on the haulageway with its front, or cutting end, toward the working face, and it will not be necessary to turn it around.

When the machine is properly placed, a piece of rope about 15 feet long is tied securely to the center of the cutter head and allowed to hang loose. The two log chains are then passed down through the machine in front of the motor and brought back underneath, so as to hold both the stationary and sliding frames from slipping when hanging in the shaft. The cage is then lowered and the ends of the chains securely fastened to the cage platform. When all is ready, the cage should be slowly and carefully raised, the machine being steadied by holding the loose rope until it finally hangs below the cage in the center of the shaft. Bars may be used at the cutter head to pry this loose in case it gets caught while the machine is being raised.

When the machine has cleared the timbers, these are removed and the cage slowly lowered until the cutter head is within a few feet of the lower landing, when it should be stopped. Heavy timbers should be placed across the shaft at this landing as above. The men below now seize the rope attached to the cutter head and pull this end of the machine out into the landing, the cage being again slowly lowered, and the machine allowed to settle on to the timbers provided to receive it. The chains are now removed and the machine is moved forwards clear of the shaft. The truck is lowered in practically the same manner as the machine.

47. Operating the Machine.—The machine, mounted on the truck, is hauled to the working place where it is to be used. On the truck are loaded skids, on which the machine is slid from one side of the room to the other when cutting, reel, tool box, jacks, blocks, rear jacks, etc.; these are unloaded by the machine runner and his helper. The skids are placed parallel to the working face and at such distance apart that one will come under the forepart of the machine while the other is under the motor. Much time and hard labor are saved by arranging the truck, blocks, and rollers so that the machine may be moved in the most direct manner possible to the left-hand corner of the room, where the work of cutting is to begin. To do this, the front of the truck is first slewed to the left, and a block placed under it just high enough so that when the machine is started forwards and its weight comes on the block it will tip the truck slightly and carry the machine forwards on two or three properly placed rollers, as near as possible to the desired position in the corner of the room. Where the track is removed some distance from the left rib, or where the floor pitches to the right, or where the floor is rough, wet, or soft, the machine may not move thus the whole distance to the rib; but some distance will be covered at least, and much heavy work with the bars saved.

48. The Rib Cut.—In making the first, or rib, cut with a machine of the breast type, it is well to square the machine with the side of the rib, or as near this as possible in order to preserve a straight, smooth rib.

The helper always works at the left of the machine when it is running, except when making the first cut, when there is not space enough between the machine and the rib to receive the shovel for cleaning away the cuttings; he should then take a position either in the rear or on the right side of the machine.

49. Placing the Skids.—When the machine is in place, the runner raises the rear end with a bar while the helper shifts the skid as far to the right as he can; this will permit the machine to move to its next position, for making the second cut, without again placing the skid. It is also important to place one skid as far toward the rear of the machine as possible, to avoid the bending effect that is exerted on the machine when the skid acts as a fulcrum, with the weight of the machine on one side and the downward pressure of the rear jack on the other; Fig. 25 shows the correct position of the machine and the two skids on which it rests. The second skid is placed in line with and overlapping the first about a foot. At this point, some runners place a block or wedge under the left side of the machine in the rear, to hold it more securely against the lateral pressure or kick of the cutters as they advance into the cut.

50. Setting the Jacks.—In setting the jacks, the helper throws the front jack forwards to the face to mark the location of the jack-hole. He then turns the jack out of the way, and cuts away any loose or projecting coal at the place marked, and makes a pocket in the face to receive the jack, which is now swung back and firmly screwed in place. The wire connections are then made as before described, the runner in the meantime setting the rear jack. This is raised

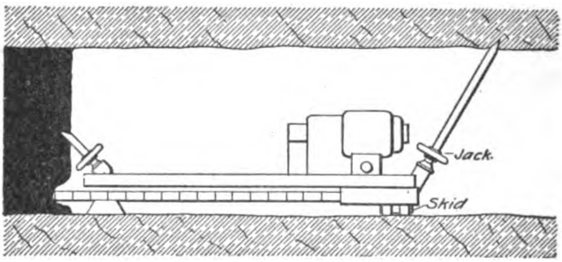


FIG. 25

against the roof, to mark the location of the hole, which is then cut and the jack screwed firmly in place. After the machine is oiled and the connections made, the work of cutting is begun. The runner starts the machine and watches it closely until it has completed its cut. Where the machine is not provided with a front trip to prevent the sliding frame moving too far out, care must be taken to properly gauge the travel of the frame, that the machine does not "run through herself" and break some part. Under favorable conditions, the cut is completed without further effort on the part of the runner, but when there are sulphur balls in the coal or timber to work around great care is necessary.

51. Obstructions to Cutting.—As shown in Fig. 26, the machine may be started at *a*, near the floor line of the coal, and when in but a short distance it may encounter a sulphur ball *s* and have to be withdrawn, jacked up higher, and started again, with possibly the same experience. The trouble does not end here, for after the room is cut the miner often has to be paid extra for taking out the bottoms left by the machine.

52. Some of the difficulties of working among timbers are shown in Fig. 27. The usual cuts at right angles to the face are shown at *a*, *a*, *a*; but to cut around the prop *b* two

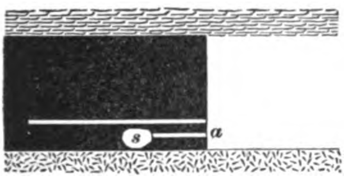


FIG. 26

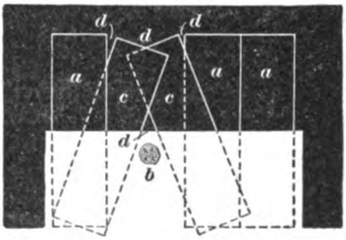


FIG. 27

oblique cuts *c*, *c* have to be made, leaving *sprags*, or uncut coal, at *d*, *d*, *d*. These make shooting very difficult and a great deal of slack results in the coal.

53. Machine Troubles.—There is a peculiar rhythm of the running parts of a machine in motion, with which the runner soon becomes familiar and develops a sense of its meaning. The change of sound from high to low voltage is easily recognized, and the click of a broken cog, or the rattle of a loose joint is quickly detected. The recurrence of an unfamiliar sound in the running of the machine should at once be investigated to avoid a serious break. If the trouble is beyond the power of the runner to correct, he should report it to the machine repairman and receive such assistance as he requires to remedy the trouble.

54. Expert Practice.—After a runner and helper become thoroughly experienced in the use of a machine, in favorable places part of the time while the machine is making the cut can be utilized in preparing for the next cut; and in this way some record runs are made by experts. As soon as the machine is well under way, the runner determines about where the next rear jack-hole will come, and has the cut made and ready for receiving the jack by the time the machine has finished its cut. The helper can also stop shoveling when the cut is about two-thirds in, and, taking his pick, start to square up the face and make the front jack-hole for the next cut. Completing this, he loosens and throws back the front jack, and has his bar under the corner of the cutter head, ready to shift the machine over as soon as the cutters clear the cut. Now, throwing his weight on the bar, the cutters still running are raised and brought in contact with the solid wall, against which they act to assist the men in shifting the machine to its next position. To do this, and to give the runner more time to shift his end, the machine is kept running continuously, from start to finish of a place. As the machine clears from the cut, the runner loosens the rear jack and swings it out of the way, or lays it on the floor ready for the next set. Taking his bar, he throws the rear end of the machine when the helper starts to throw the front end. In this way, the machine is moved evenly without binding. The same process is repeated for each succeeding cut.

When a room or place is finished, there should be no delay in returning the machine to a position for loading it on the truck with the tools, skids, etc., ready to be hauled to the next place. Each one should have a care in regard to the way he uses his bar, that he may not neutralize the efforts of his mate through a too ambitious throw, thereby wasting time. The thickness of the seam greatly influences the ease with which a machine can be handled; and in a very thin seam it is sometimes advantageous to have three men to handle it.

55. Care of Tools.—Much time is lost in hunting for tools that are laid down where last used instead of being put in their place where they can be readily found when needed again. "A place for every tool, and every tool in its place" is a good maxim in mine work. There are certain tools, as bar, jacks, etc., that may properly be left on the floor where they will be required for use, but wrenches, hammers, and other small tools should be laid aside in one place when not in use. A pick or a shovel should be stood against the face where it will be needed. If these precautions are not observed, the work will be much delayed, and a misplaced tool may cause a serious break in the machine by being caught in the chain or other moving part, or may be covered by the cuttings and lost.

56. Division of Labor.—In the operation of the machine, the runner and the helper should each have his work to perform, and should understand what are his particular duties. While the entire machine is in charge of the runner and the helper is subject to his orders, there is less confusion and loss of time when each man knows his duties and performs his proper work. In general, the motor end of the machine is in charge of the runner, while the cutting end should be looked after by the helper. Confusion in this matter causes delays and prevents attainment of the best results.

Duties of Runner.—A runner's duties, in a general way, may be stated as follows: (1) starting the machine from the truck; (2) placing and operating completely the rear end of the machine; (3) placing the rear jack; (4) connecting in the short cable; (5) cleaning the commutator; (6) oiling the motor and machine; (7) starting up the machine; (8) reversing and stopping it; (9) tightening the cutters in the chain; (10) general charge of machine repairs, under supervision of machine repairman.

Duties of Helper.—The helper's duties, subject to the direction of the runner, are: (1) general charge of the bits; (2) placing same in the chain; (3) placing and operating the front end of the machine; (4) placing the front jack; (5) shoveling back the cuttings from the machine; (6) making the circuit connections of the long cable; (7) assisting in repair work as directed by the runner and machine repairman.

57. Operating the Chain Shearing Machine.—The operation of the chain shearing machine differs from that of the chain breast machine only in that the shearing machine makes a vertical cut from top to bottom of the coal along one of the ribs, while the chain breast machine cuts along the bottom of the coal or near the bottom, in the plane of the seam.

58. Operating the Long-Wall Machine.—The long-wall machine cuts continuously along the face of the coal. There are usually two men required to run this machine, sometimes three. The machine runner's duty is to have charge of the machine, to regulate and control the speed of the machine and the cutting wheel, chain, or arm, as it may be, in its progress along the face of the coal. The helper's duty is to take care of the cuttings, cable, etc., to assist in placing the rail and jacking it securely in place, when the machine is of the type that runs on a rail, and to perform any other duties that are needed.

THE STANLEY HEADER

59. In the **Stanley header,** Fig. 28, the driving and the feeding mechanisms are placed on a massive frame *a* that

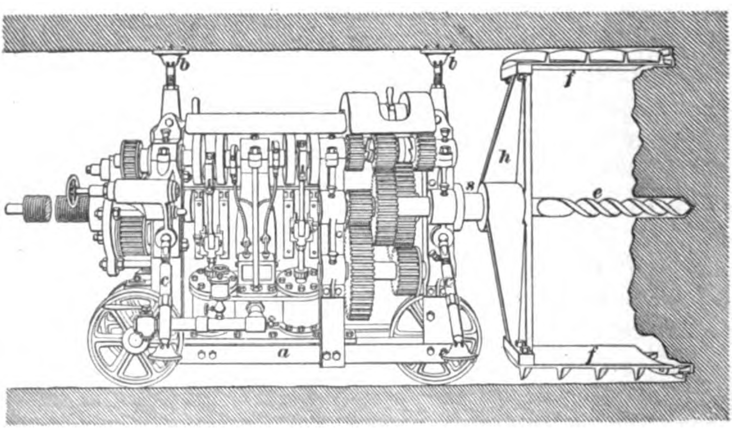


FIG. 28

is mounted on wheels. When the machine is in place ready to commence work, it is held fast by the top jacks *b*, *b* and the side ones *c*, *c*. At the end of the main shaft *s*, an auger drill *e* is placed for the purpose of steadying the cutter frame while the machine is working. The cutter frame consists of a large revolving cross-head *h* carrying two arms *f*, *f*, in the ends of which the cutters or bits are set. The driving mechanism is so constructed that different rates of speed of the cutter frame can be produced as desired for a given rate of feed advance, on coals of varying hardness. As the main shaft rotates, it advances, turning the cutter frame. The bits cut out an annular groove from 3 to $3\frac{1}{2}$ inches wide, forming a complete cylinder of coal as deep as the arms *f*. When this is done, the machine is run back and the coal is taken down and loaded up. The machine is again set in place and another cylinder cut out.

The cuttings are forced to the front of the annular groove by the scrapers on the arms *f*, and from here they are raked to one side of the machine by a helper whenever the revolving arms are not in the way. Lumps of coal that fall from the face are also drawn to the side by the helper, and finally loaded into a car. In many of these machines, however, the cuttings and the coal that falls while the machine is working are taken from the face by a friction worm and loaded into a mine car by means of a conveyer or elevator.

The principal use of this machine is for entry driving, where the work must be pushed rapidly. It is especially advantageous for prospecting a piece of coal, as an entry can be driven a long distance as a single entry, and with no other ventilation than that caused by the air used by the machine.

60. Capacity.—The Stanley header can cut out a cylinder of bituminous coal 4 feet in diameter and 5 feet in length in 15 minutes, and after making the necessary allowance for removals, a rate of advance equal to 75 feet per shift of 10 hours is accomplished. Where it is necessary to drive wide entries, two machines may be worked side by side, thus driving two parallel entries that nearly intersect each other. The thin pillar left between them can easily be cut out with a pick. If the coal could be removed as quickly as the cutting is done, the machine could advance an entry 12 feet wide 25 feet in 10 hours. The entries thus cut can be widened out to the desired height and width by the use of the pick. Impurities, such as sulphur balls, existing in coal hamper the use of the Stanley header, and when they are present its progress cannot be as favorable as in coal favorable to mining. An average cost per lineal foot of entry for a cylindrical cut alone should not exceed 25 cents.

PICK MINING MACHINES

UNDERCUTTING PICK MACHINES

61. General Features.—The general appearance of and the method of operating **pick mining machines** are shown in Fig. 1. The construction and mode of action of these machines differ entirely from the chain machines already described. With the chain cutter and long-wall machines, either electric or compressed-air power may be used, although electricity is the more common. But though many attempts have been made to build pick machines operated by electricity, at the present time very few of these are in use. The general construction and action of the pick, or puncher, machine is similar to that of the rock drill operated by compressed air. The features that are common to all pick machines are a heavy piston about 4 inches in diameter, usually provided with split piston rings and attached to a piston rod on which the pick is fastened either directly, Fig. 30, or by means of a pick extension, Fig. 1. A heavy piston rod and pick are necessary because the energy of the blow struck by the pick depends on the weight of the moving parts as well as the air pressure on the piston. The essential point of difference in the several makes of pick machines is in the valve.

62. The **Ingersoll-Sergeant pick machine**, Fig. 29, consists of a heavy piston *a* about 5 inches in diameter provided with split piston rings *b*, *b* and attached to the piston rod *c*. The machine rests on the wheels *e* and is controlled

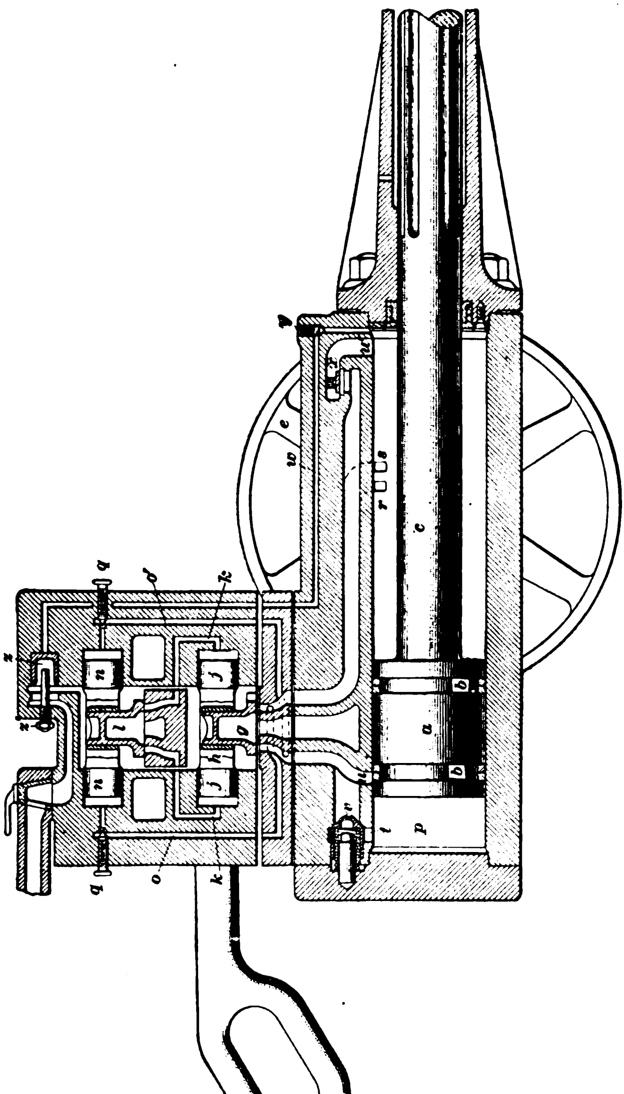


Fig. 29

by the handles *f*. The main slide valve *g* is practically a **D** valve, which is operated by the valve *h*, the ends of which are turned to form single-action plungers *j* about 2 inches in diameter. These plungers fit into cylinders and form a spool valve, and by the air being admitted to these cylinders alternately through the passages *k*, the valve *g* is moved and hence the piston *a*. There is a second **D** valve *l*, called the *auxiliary valve*, with an almost exactly similar double-ended plunger arrangement, the two plungers *n* fitting into two more cylinders. The ends of these cylinders are connected, by small passages *o*, *o'* to the air passages, to the main power cylinder *p*. The passages *o*, *o'* cross over so that *o* connects with the front, or right-hand, passage to the main cylinder and *o'* to the back, or left-hand. Consequently, when live air is admitted to the front, or right-hand, end of the main cylinder, some of it escapes up *o* and, acting on the end of the plunger *n*, forces the auxiliary valve *l* to the right. This admits live air through the passage *k* to the left, or back, of the plunger *j* of the valve *h* and moves the valve *g* to the right, admitting live air to the main cylinder *p*, and forces the main piston *a* to the right; at the same time, some live air escapes up *o'* to the piston *n* of the auxiliary valve *l* and reverses the valves *l* and *g*, which in turn reverse the motion of the main piston, and so on. The ports and valves are so arranged that it is impossible to center them, regardless of their respective and relative positions, and the whole form what is known as a relay mechanism. The left-hand, or back, port of the main valve is larger than the other, and therefore the forward stroke is more powerful. The exhaust air, which moves the auxiliary valve *l*, passes two little valves *q*, *q*, one for each of the two plungers *n*. By means of these adjusting valves, the operator can regulate the rapidity of the movement of the auxiliary valve, and hence also the movement of the main valve. When the auxiliary valve *l* moves, it immediately opens one of its ports and allows air under pressure to move the main valve *g*, and this, in turn, admits full pressure of air to the main piston *a*. The result is that, no matter how slowly the auxiliary valve moves, when the main piston does move, it does so with a full and powerful stroke. This enables the operator to reduce the number of blows per minute, but the force of each blow is in no way diminished.

To prevent the piston knocking against the cylinder heads, a cushioning arrangement is provided as follows: The ports *r*, *s* open into the cylinder comparatively close together along the line of stroke, while those marked *t*, *u* open into the back end of the cylinder a considerable distance apart along the line of stroke. When the piston *a*, moving toward the back of the cylinder, passes the port *u*, the air is trapped and compressed in the end *p* of the cylinder, the port *t* being closed by the valve *v* operated by a spring, and the cushioning air is retained until the piston *a* is thrown forwards by the expansion, and the pressure in *p* is reduced below that of the live air, which then opens the valve *v* and, entering through the port *t*, forces the piston forwards, thus opening also the port *u*; and the piston is driven forwards with full force. The exhaust ceases when the piston *a* closes the port *s* in the front portion of the main cylinder; the pressure then rises in that end, but before the piston completes its stroke the head of the main valve *g* permits the live air to enter the passage that connects through the port *u'*. To reach this port, the air must lift a small valve *x* against the pressure of a spring and the cushioning pressure in the cylinder, and as this can take place only when the cushioning pressure is low, live air is not admitted until the back stroke has partly proceeded. If, on the other hand, the cushioning pressure is very high, as, for example, when the pick misses the coal, when it may be 200 to 300 pounds to the square inch, this pressure lifts a small valve *y*, called the *governor passage valve*, and is transmitted through the passage *w* to the governor valve *z* and moves it against a stop *z'*, which can be so adjusted that the valve will partly or entirely cut off the main air supply. The stop *z'* can be set at any desired point to automatically cut off any fractional part of the air during the time the pick is not cutting coal, and the machine will run lightly and at a reduced speed and force until such time as the pick is again thrown against the coal, at which time the governor valve automatically opens and the machine is brought into action with full pressure and force, without any annoyance or inconvenience, and introducing an element of safety and confidence for new men learning the work. Experienced men who swing the machine or the pick away from the coal less frequently can throw this governor out of gear so that it becomes inoperative, if they so desire. The whole arrangement is simple and entirely automatic. The throttle device, therefore, can be opened wide and left so during a whole running period with the assurance that the governing valve will take care of the supply at all times and under all conditions.

As the movement of the valve is controlled by a permanent arrangement of the ports, admitting and exhausting pressure alternately on both ends of valves and pistons, this arrangement of ports and valves makes it an independent movement, and the piston can be blocked in the cylinder at mid-travel without affecting the valve, which will run on continuously, admitting and exhausting in the same manner as if the piston were moving in harmony with it.

63. Picks.—The style of the pick used in this machine is usually that of a steel shaft, octagon or round, tapered at one end to fit the socket in the extension. The other end is flattened and swaged out in the center on one side, the center being cut out in the form of a **V**, leaving the shaft with double points. The swaging and flattening are all done on one and the same side of the pick, and in moderately soft coal care should be taken that the pick points—when dressed, squared up, and tempered—are lined with the machine piston rods, with the points from $\frac{1}{4}$ to $\frac{3}{8}$ inch off the center line of the piston rod. In very hard coal, it is necessary to flatten both sides of the pick, bringing the points nearer the center line of the piston rod. The picks should invariably be dressed up to a cutting edge in the crotch, and the two points dressed square, in the same manner as a miner's pick, except that they should be made larger in order to stand the heavy blow of the piston. It sometimes happens that the pick points break frequently in starting a new machine plant, especially where there is considerable sulphur, black jack, pyrites, etc., in which case it is recommended to temper the pick points in black oil. This can be easily accomplished by making a box 12 inches high, 8 inches wide, 2 feet long, kept half full of black oil, in which all the picks stand on the point after being given a cherry-red heat.

Although the common double-pointed pick is the one most commonly used, it is sometimes necessary to change the shape of the picks in order to meet the conditions; but this can only be accurately determined by repeated experiments made by experienced men. It is customary to use the double-pointed pick for shearing; but when used for this purpose, the points (when the pick is socketed in the extension) are set horizontally and parallel with the wheel trunnions (flat side up) instead of vertically, as is the case when undercutting. A four-pointed pick is sometimes used for shearing, especially in backing up a cut where there are sulphur and slate bands to cut through.

Blacksmiths should be careful, when sharpening picks, to see that the points are spread far enough apart to insure perfect clearance; otherwise, if the coal is tough or woody, the pick will stick in the coal and cause trouble and loss of time to the machine runner. The better and nicer a pick point is dressed and tempered, the more coal it will cut before it comes back to the blacksmith.

64. The **Harrison mining machine** differs from the usual type of pick mining machine principally in the valve that controls the entrance of the air to operate the piston to which the pick is attached. Fig. 30 (*a*) shows a vertical section of the Harrison machine partly in perspective; Fig. 30 (*b*) is a plan of same; Fig. 30 (*c*) is an enlarged view of valve and air passages shown in Fig. 30 (*b*); Fig. 30 (*d*) is a perspective view of the rotary valve; Fig. 30 (*e*) shows an arrangement of air passages under Fig. 30 (*d*); and Fig. 30 (*f*) shows details of parts.

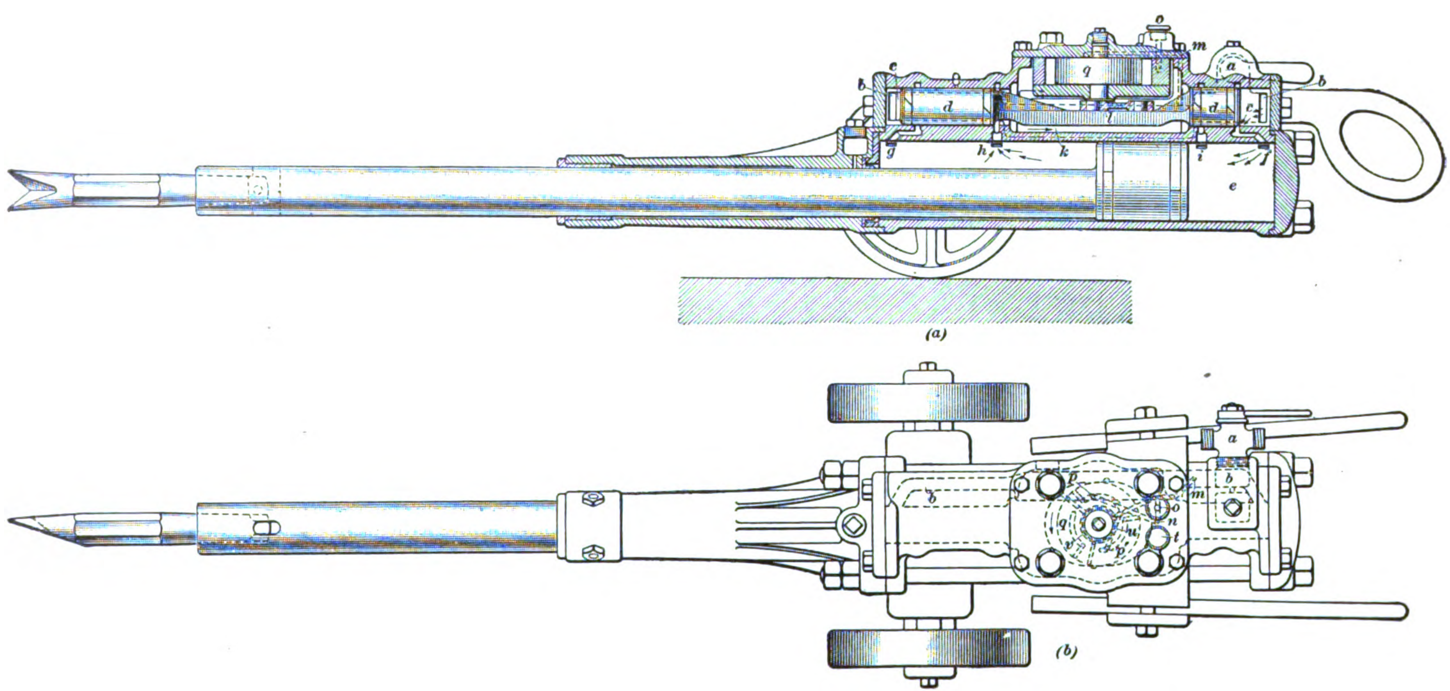


FIG. 30

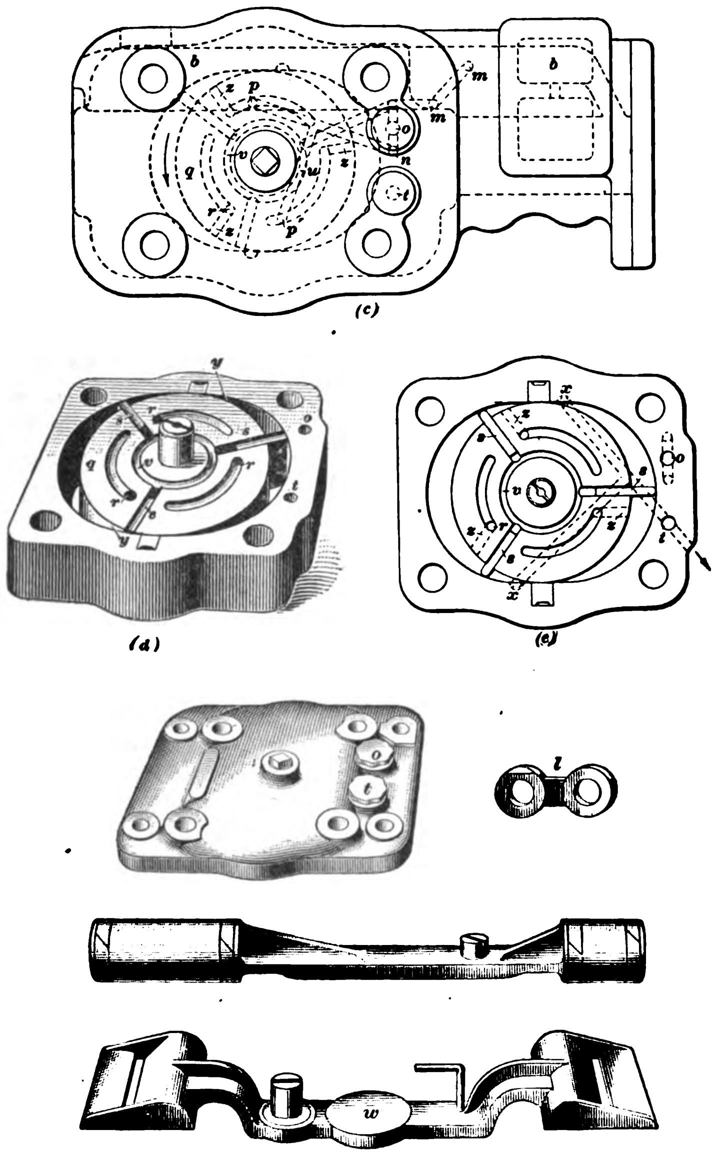


FIG. 30

Referring to Fig. 30 (*a*) and (*b*), the air enters the machine through a valve *a* in the side and passes into a duct *b* running from one end of the machine to the other; it then passes into the spaces *c* at the ends *d* of the piston valve, from which it is admitted to the main cylinder *e* through the ports *f* and *g*. The air exhausts from the cylinder *e* through the ports *h* and *i*, into the central chamber *k*, where is located the crank-movement by which the piston *d* is operated. In some forms of this machine, a D slide valve of the form shown at *w*, Fig. 30 (*f*), is used to control the admission of air to the main cylinder *e* instead of a piston valve. This crank-movement is connected to the piston *d* by a connecting-rod *l*, shown in detail in Fig. 30 (*f*), and is operated by a three-winged rotary engine, Fig. 30 (*b*), (*c*), (*d*), and (*e*), spoken of hereafter as the *rotary*.

The air for driving this rotary comes from the duct *b* up through a small port *m*, *m*, Fig. 30 (*a*), (*b*), and (*c*); it then passes under a throttle screw *o* to a point *n*. This throttle screw *o* is to enable the operator to regulate the amount of air passing through the rotary. From the point *n*, Fig. 30 (*b*) and (*c*), the air passes up into and through the rotary cover, to the points *p* and *p'*, Fig. 30 (*b*) and (*c*), which are the two intake ports of the rotary, Fig. 30 (*d*).

The central disk *q* of the rotary has depressions countersunk in the top side, as shown in Fig. 30 (*d*). At one end of each of these depressions, a port *r* passes down about half way through the disk, then out through the side, going out back of the gates or wings *s* as shown at *z*, Fig. 30 (*e*). Whenever the depressions in the disk come under the points *p* and *p'*, the air enters them, passes down through the disk by the ports *r* and goes out behind the gate or wing *s*, thus forcing the disk around, as the air pressure will always be acting on two of the three wings. The exhaust from the rotary is through the bottom of the rotary chest at points *x*, Fig. 30 (*e*), which are in the lower cover directly under the points *y*, Fig. 30 (*d*). When the gates pass these points, the air passes out through the lower cover through ports *x*, shown in Fig. 30 (*e*). In passing out, the air passes under another regulating screw, called the *rotary throttle screw t*, Fig. 30 (*b*) and (*e*), and by screwing this down the exhaust can be choked and the speed of the machine partly regulated. As the center disk *q* is a solid casting, it acts as a flywheel and gives an even motion to the valve action and prevents the tendency of the machine to run faster, or *race*, when the pick misses the coal.

The gates *s* of the rotary are forced out by air pressure. From the intake port to the rotary at a point *u*, Fig. 30 (*b*) and (*c*), the air is admitted to the depression *v*, Fig. 30 (*c*) and (*d*), running around the disk *q* just back of the gates *s*, and keeps them forced out at all times. In the bottom of the disk *q* are countersunk recesses equal to the depressions countersunk in the top of the disk; the air is admitted into these through the disk and back of the rotary gates. This air balances the disk and largely does away with friction on both top and bottom of it.

65. The **Sullivan pick machine** is shown in section in Fig. 31 (*a*), while the levers for regulating its speed and stroke are shown in Fig. 31 (*b*). The operation of the Sullivan pick machine is as follows: The piston *1* works in the cylinder *2* and is provided with spring rings *3*; the piston rod *4* is packed at the front end by the leather *5* and passes through the bushing *6*, which can be replaced when worn and which is drilled with oil holes to admit oil from the reservoir *7*; *8* is a plug that can be removed to fill the reservoir. The front end of the piston rod passes through the babbitted guide *9*, and as this part of the piston rod is square, the piston is prevented from turning. The air chest *10* contains two valves: a modified flat slide valve *11* that controls the admission of air into the cylinder *2* by separate admission and exhaust ports, and a differential piston *12* that operates the valve *11*.

In the sectional view, Fig. 31 (*a*), the piston is near its extreme travel to the left, the valve *11* is at extreme left position and air under pressure is being admitted from the air chest *10* through the inlet port *13*, thus driving the piston

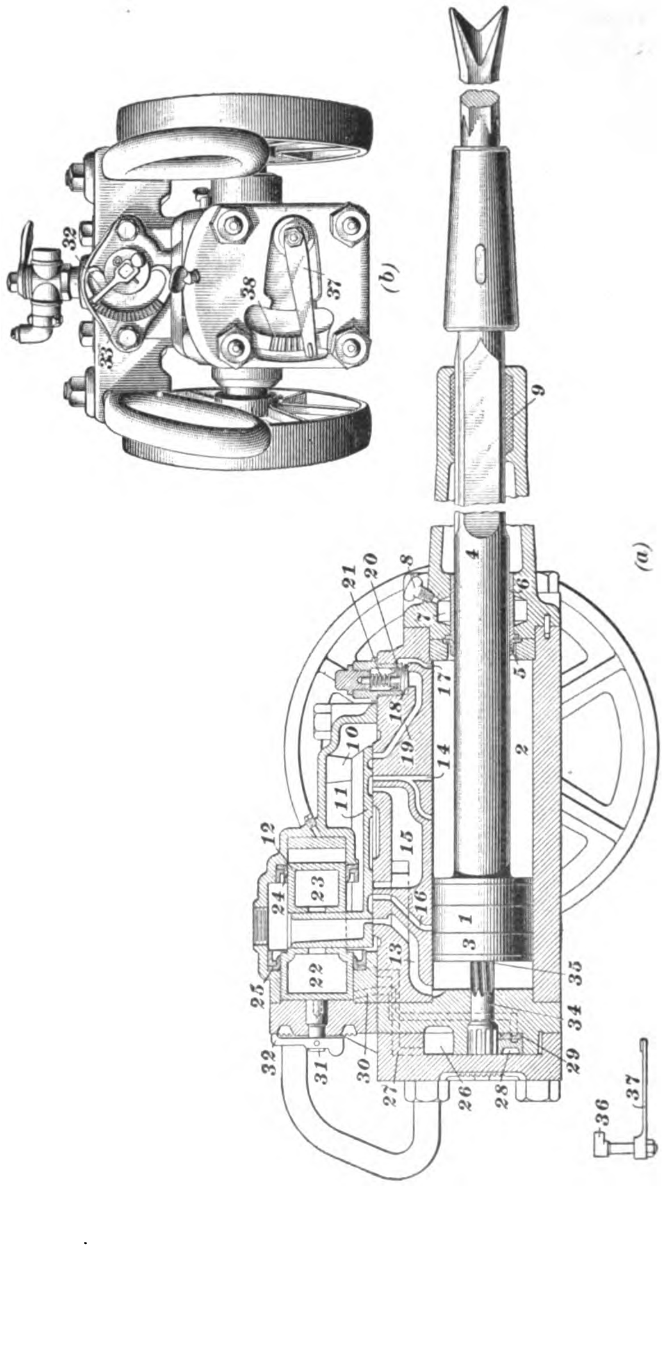

(a)
(b)
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Fig. 31

forwards. At the same time, air is exhausting into the exhaust chamber *15* through the port *14*, which has two openings into the cylinder *2*. *16* is the exhaust port for the back end of the cylinder.

The admission port *17* for the front end of the cylinder connects through the governor valve *18* and the port *19* to the air chest *10*.

When the valve *11* and the piston *1* are at the extreme right, the exhaust port *14* is closed and compressed air enters the admission port *19* through a port in valve *11*. The air pressure in *19* then raises the governor and the air passes freely to the front end of the cylinder.

The governor *18* acts not only as a check-valve to form an air cushion in the front end of the cylinder, but it also prevents the piston speed from becoming too great, by allowing the air compressed in the front end of the cylinder to pass the leather *20* into the space *21* above it. The air in this chamber then holds the valve *18* on its seat, preventing the admission of any live air, when the valve *11* opens the admission port *19*, until the pressure above the governor *18* has fallen, due to the escape of the air from the front end of the cylinder through a small passage in the valve *18*. The valve *18*, therefore, will not lift while the compression is high, due to the pick missing the coal, and the valve may not rise at all to admit live air, the compression alone being relied on to return the piston to the back end of the cylinder. If the pick strikes the coal before the piston head reaches the cushion chamber, the air in *19* raises the valve *18* and passes into the cylinder, thus driving the piston back.

The piston valve *12* that controls the movement of the flat valve *11* fits over two lugs on *11*. The valve *12* has ends *22* and *23* of different diameters that move in closely fitting cylinders, packed by leathers *24*, *25* to prevent the leakage of any live air from the air chest to either end of the piston valve. If both ends of the piston valve *12* were open to the exhaust air, the valve would be held in its position to the left as shown, due to the greater pressure on the large end *22*. The small end *23* is connected permanently with the exhaust, and the motion of the valve is controlled entirely by the admission or exhausting of air from the end *22*.

The chest *26* is supplied from the air chest *10* with air at the pressure of the air in *10* through the passage *27* shown dotted in Fig. 31 (*a*). This air passes from *26* through the valve *28*, the valve seat *29*, and the passage *30* to the regulating valve *31*. This valve *31* is held in position by a lever *32* that fits notches *33* in the cover. Varying the size of the opening through which the air passes, this valve varies the speed with which the piston valve *12* and flat valve *11* move to the right.

The position of the valve *28* that controls the passage of air to the piston valve is controlled by the gear on the rifle bar *34*. This rifle bar passes through a rifle nut *35* in the piston so that the piston valve and, therefore, the flat valve are controlled by the position of the piston. When the piston is near the back head, the valve *28* covers the port admitting air to the piston valve. As the piston moves toward the front head, the valve *28* is moved until it uncovers this port; and the air acting through the passage *30* on the head moves both the piston *12* and flat valve *11* to the right, admitting air to the front end of the cylinder *2* and causing the backward stroke of the piston. When the piston approaches the back head, the valve *28* also opens the exhaust from the piston valve, causing the piston and flat valve to return to the left ready for the forward stroke.

The ports controlled by the valve *28* are in the seat *29*, which can be moved by the single tooth gear *36* operated by the lever *37*, held in position by notches *38* on the chest, Fig. 31 (*b*). When the lever *37* is in its bottom position, the ports are placed so that the piston valve will be moved to the right earlier in the stroke than when the lever is up. This tends to give an earlier cut-off in the main cylinder, depending on the size of opening through valve *31*. Levers *32* and *37* together control the speed of the machine and also the force of the blow.

By adjusting the levers on the rear of the cylinder head, the air may be used at full pressure for from one-half to five-sixths

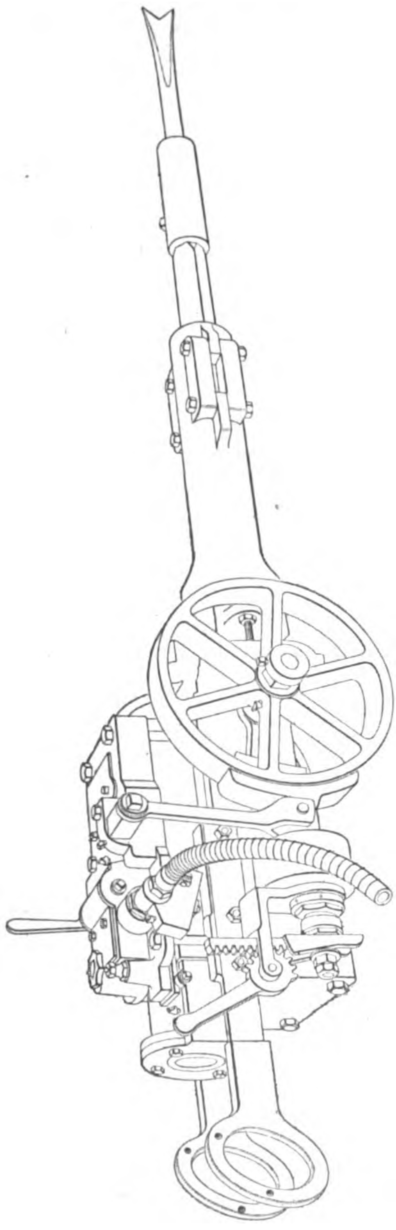


Fig. 32

of the stroke and then cut off, the stroke being finished by the expansion of the air. The machine has a quick forward stroke and a comparatively slow recovery, giving the operator time to properly direct the blow. As the valve motion is operated by the piston, if the pick sticks, the cylinder becomes the reciprocating part and the machine "kicks." The makers claim that, instead of being a disadvantage, this feature is one of the good points, as the machine will quickly work itself loose, and a skilful operator can often take advantage of this to save heavy lifts in moving the machine. The machine exhausts from either or both sides as desired, so as not to interfere with the laborer working alongside.

66. The **Yoch machine**, Fig. 32, is similar in many respects to those already described. The piston head is easy of access for packing and can be removed if necessary.

Air is admitted to the piston by an ordinary D valve, which also carries a cut-off valve that opens ports for admitting air to the air chest and is set to close these ports at seven-twelfths of the stroke of the piston, allowing the remainder of the stroke to be made by expansion, thus relieving the runner from much of the violent jar, and economizing in the use of air. The machine operates successfully at a pressure varying from 40 to 100 pounds. The operating pressure in the machine is controlled by a patent regulator which does away with the necessity of closing the throttle valve between the hose and the machine, and permits it to remain open until the machine is ready to be moved. There is also a patent lubricating device by which the oil is carried with the current of air and thoroughly lubricates the entire inside of the machine. It is the usual custom to balance a machine on the wheels so that when the piston is at half stroke the machine is in perfect balance on the trunnions and can be tilted easily either up or down. There is, however, an arrangement provided by which the balance can be adjusted to suit the operator.

67. The **Herzler & Henninger machine** is similar in many respects to those already described. The piston cushions on air, and there is a regulator for varying the length and speed of the stroke and the force of the blow. The stuffingbox on the front head can be packed without removing the head, and the balance of the machine may be adjusted by loosening a nut and slipping the hub backwards and forwards in a slot cast in the side of the cylinder. The machine will not race when the pick misses the coal, and the regulation is such that the speed is steady and uniform.

68. Fig. 33 shows an **electric pick machine** that has a reciprocating piston actuated by a spring and cam, the spring striking the blow and the cam drawing the piston back. The cam is driven by a motor *m* of the toothed Gramme-ring type. The important feature is the manner of connection of commutator to coils, there being no wire connections at this point, which makes the armature as nearly indestructible as possible. The pick *p* is attached to the outer end of the piston, which is supported by the sleeve *s*. The machine weighs 750 pounds and is mounted on wheels *w*. It is controlled, while working, by the handles *h*.

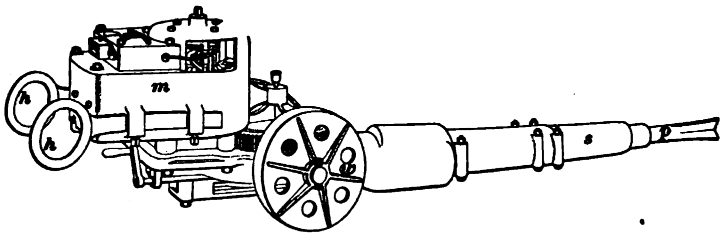


FIG. 33

Its length is 7 feet and its width over the wheels 21 inches. The piston makes from 175 to 225 8-inch strokes per minute.

PICK MACHINES FOR SHEARING COAL

69. Fig. 34 shows a pick machine mounted on large wheels for shearing or making a vertical cut in the coal face. This machine is similar throughout to the pick machines described for undercutting, except that the wheels are larger, being from 30 to 40 inches in diameter. Mounted on such wheels, it will make a cut or shearing of $4\frac{1}{2}$ to $5\frac{1}{2}$ feet deep and an equal height, or higher if placed on a support as shown in the figure. Fig. 35 shows this machine in position to make a shearing on one side of an entry face. The lower portion of the cut is sometimes made wider than the upper, so that the wheels can be run into it where a deep cut is required, but this is not often necessary. The operation of this machine is the same as that of the undercutting pick machine, and where the place is to be both undercut and sheared, two pairs of wheels can be carried on the truck used for carrying the machine, and these changed from time to time as desired.

70. The **Sullivan pick, or direct-acting, shearing machine**, Fig. 36, is especially adapted for driving entries.

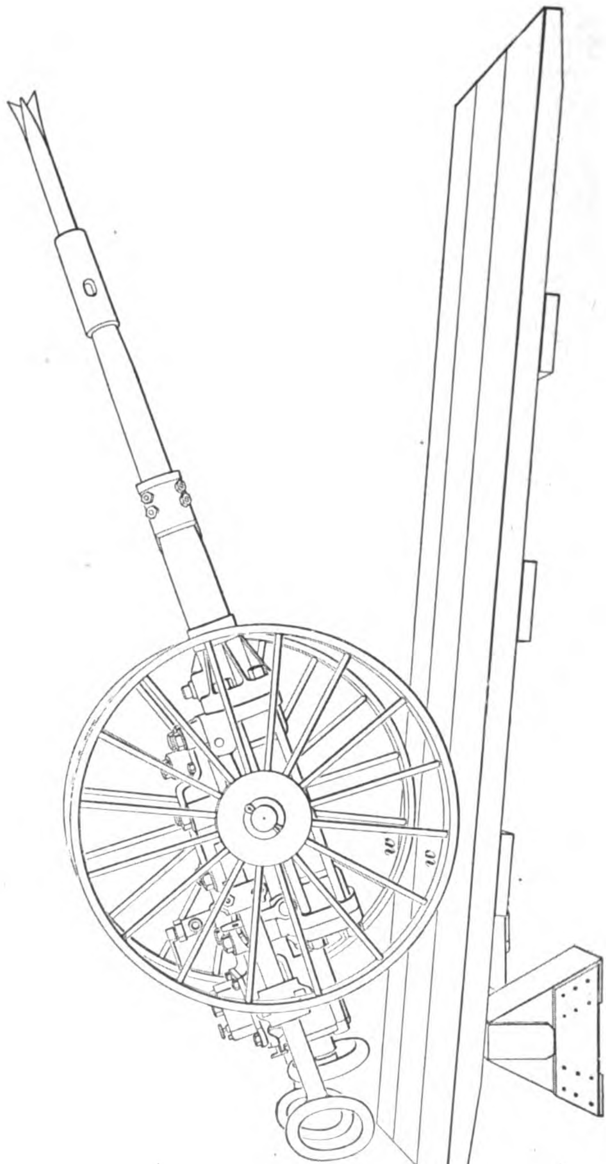


Fig. 34

The principle of the machine is essentially the same as that of the pick machine already described. The cylinder *c* is supported on pivots on the frame *f*, so that it can move through an angle of about 60°. The arm *j* supports the cutter rod *c*, which is an extension of the piston rod *p* and carries the bit *b*. The operator directs the blows of the pick by means of the lever *m*, which works a system of gears engaging with the curved rack *r*. A special piece of track

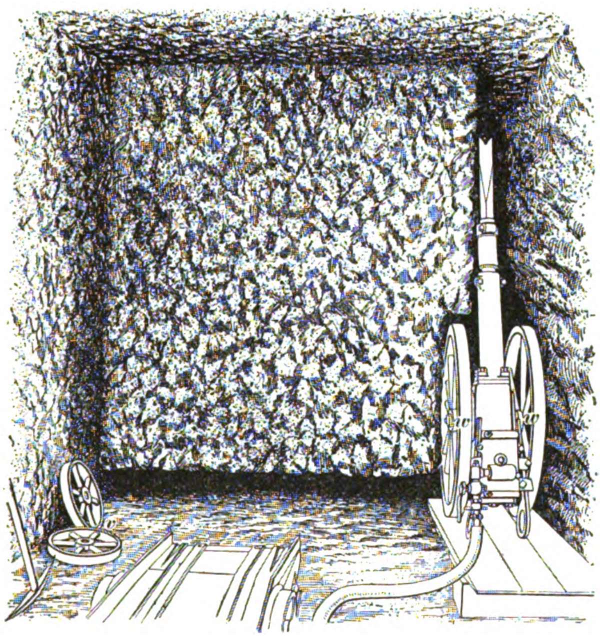


FIG. 35

bound together with iron ties is kept in advance of the common track for the machine to stand on while at work. The chain *s* fastened to the end *k* of the rail and the bottom of the rear jack *n*, is used to hold the machine in place and to advance it by turning the lever *l* whenever a cut has been made from top to bottom about equal in depth to the length of the stroke of the piston. A special form of bit or pick shown at *b* is generally used in this machine.

This machine will make a shearing in the center of the entry 6 inches wide, from 5 to 8 feet deep, and from 4 to 10 feet high. It strikes quickly, about 300 strokes per minute, and weighs 1,600 pounds. A great advantage with this form of shearer is its ability to work above and below large obstructions and around small sulphur balls, the former being broken and removed later, and the latter being cut out by the machine.

71. Pick Machine Used for Long-Wall Work.—The pick machine is used for long-wall work only when unfavorable mining conditions exist in the coal, or where the mines

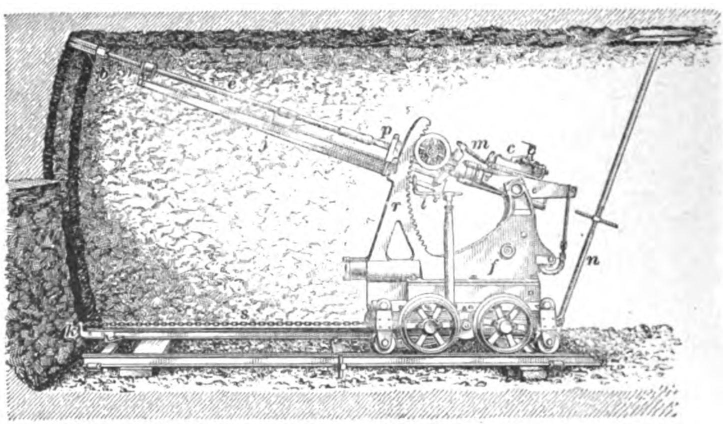


FIG. 36

are gaseous. The advantages, as to greater output, of machines especially built for long-wall work, such as those already described, are so great that they are always preferable to the pick machine wherever conditions will permit their use.

72. The **Radialax coal cutter,** Fig. 37, is intended chiefly for shearing, for cutting entries, and other narrow places, and for removing slate or clay bands in the coal. In its construction and operation, it is very similar to a long-stroke rock drill of the Ingersoll-Rand pattern. The bits are of the form shown in the figure. They are fitted on the ends of steels of different lengths, which, in turn, fit into a chuck on the end of the piston rod. The coal cutter is supported on a column similarly to a rock drill, and as it swings on this column and can be raised or lowered, it can be used for cutting horizontally at any position in a coal face from

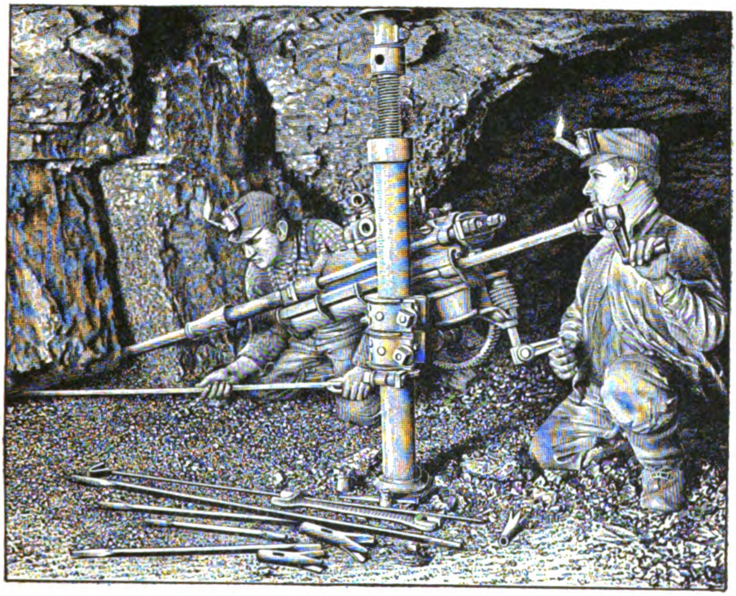


FIG. 87

the roof to the floor, and also for shearing the coal. The cut made by this coal cutter has a maximum depth of 8 feet from the face, a maximum width of 12 feet, and starting with a width of $4\frac{1}{2}$ inches at the face it diminishes to $2\frac{1}{2}$ inches at the bottom. This cutter can also be used for drilling holes in the coal for blasting.

OPERATING THE PICK MACHINE

73. In the operation of a compressed-air pick machine, two men are necessary—one skilled operator and a helper. The machine and the appliances used in operating it are conveyed to the face of the room on a low truck, or *buggy*,

Fig. 38. It is then removed from the truck and pushed to the side of the room, where the undercutting is to begin. The majority of machine runners, preferring to work mostly with the right hand, usually set up in the left-hand corner of the room. A platform 3 feet wide and 8 or 9 feet long, called the running board and made by bolting together several pieces of 2-inch plank, is placed in position before the face. The end of the platform toward the coal rests upon the floor, while the other end is raised 12 or 13 inches above the floor by causing it to rest upon a stand, or *horse*. This inclination of the board or platform toward the face

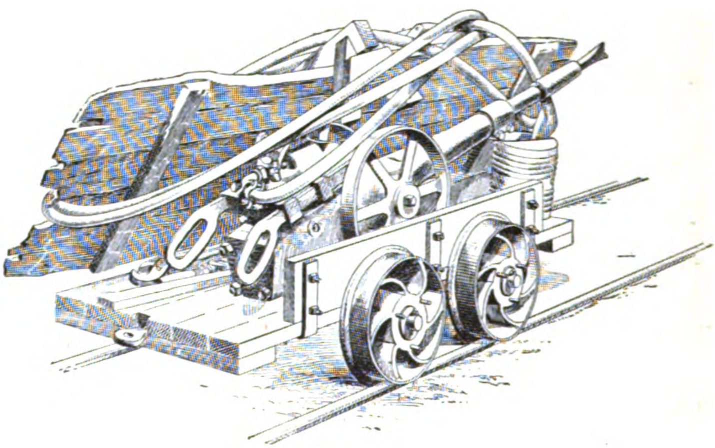


FIG. 38

helps to neutralize the recoil of the machine. At times, the board is also given a slight inclination sidewise from the opening, which enables the operator to handle the machine with greater effect and ease. The air is usually carried from the mouth of the room to the working face by a $1\frac{1}{4}$-inch pipe, and the machine is connected to this pipe by a hose about 50 feet long, a stop-cock being provided at the mouth of the room to shut off the air when not required.

The machine having been placed in position on the board and all being ready, the operator takes his place, sitting on the board behind the machine. In the operation of the machine, the work of the operator is not only to direct, but to control the force of the blow, regulating it to suit the hardness of the coal so as to give the best possible results. Some runners make the first cut, often called the tight or sump cut, by placing the running board flush against the left-hand rib, swinging the pick toward the center of the room, and sinking back into the left-hand corner. This is incorrect, however, as the helper must throw the cuttings toward the center of the room, and they must be removed by him again before the machine can proceed across the face. The better plan in sinking the tight cut is to locate the rear end of the running board about 5 feet from the rib, and the front end about 2 feet therefrom. This leaves ample room for the helper and the cuttings between the running board and the left-hand rib, and permits the runner to cut straight down into the corner, cutting always to the right, the cuttings always going to the left.

When the coal is very hard, or contains sulphur balls or other foreign matter, a long stroke is required in order to strike a harder blow; this is accomplished by pulling the machine a greater distance from the coal face. With softer coal, a short quick stroke is required, and for this purpose the machine is moved nearer the coal. A runner should avoid using the full power of the machine when cutting through a hard clay vein or sulphur band, as the powerful blow will break the pick points so quickly that more time is lost in changing picks than is lost in reducing the pressure to a point where the picks will not break. Again, by running the machine full force in such places, all the sharp picks are soon broken and it is necessary to wait for new ones. In general, pick machines strike from 165 to 225 blows per minute.

The operator, sitting on the board behind the machine, holds one or both handles of the machine firmly in his grasp. A small block of oak wood, called a *clog*, provided with a piece of sheet iron fastened to the block and bent back to protect the heel of the shoe, is strapped to the foot of the operator; with this to protect his foot, he blocks the recoil of the machine by pressing the clog against one of the wheels, thereby keeping the machine up to its work at the face of the coal. While performing his work, the miner often places his lamp inside an empty powder keg so arranged as to throw the light on the face of the coal.

A V-shaped undercut 12 inches deep is made in the face of the coal as far as the machine can reach from its first position, about 4 or 5 feet wide. This cut is then *blocked down*, which is accomplished by lowering the machine at the back, causing the pick to strike the coal at the desired height above the first cut, from, say, 8 to 16 inches up from the floor, according to the depth of cut to be made. This enables the runner to see into the cut. The helper shovels away the cuttings as they are made, using a special long-handled flat shovel. In the same manner, a second undercut is sometimes made from the same position of the board, and the coal again blocked down. At other times, the board is moved, when this can be easily accomplished, and the same operation carried along the entire face, when the machine is returned to the place of beginning and the mining then completed by repeating the process. By this means, the weighting action of the roof is made to assist the cutting, but the entire depth of undercut is accomplished in not more than two settings at any one place. The finished cut is of a V shape, tapering from 12 to 16 inches high in front to about 3 inches at the back. This enables the coal to be brought down by a comparatively small charge of powder and in good shape for loading. Each cut made at one setting of the machine is called a *board*. At times two boards, giving a width of 6 feet, are employed side by side, but this is not customary and is often impracticable, but when practicable it saves time in starting a new cut.

74. Moving the Machine.—When the entire breast has been cut, the machine is quickly placed on its truck and moved to the next cutting place. Since the pick machine is mounted on wheels, it is often simply pulled from one room to the other through break-throughs or cross-cuts by the machine runner and helper; and in this respect it is more convenient than other types of machines, which require mechanical means or the use of a mule and driver to shift them from place to place. As a rule, the pick machine is moved by loading it on a low, flat truck, Fig. 38, on which the machine runner and helper can push it without assistance.

75. Duties of the Runner.—The runner's first work is to go over his machine to see that all nuts, bolts, and joints are tight and the machine properly oiled. He takes general charge of the work as already described.

A good runner will have a number of rooms, and likewise a number of loaders, and he usually undercuts these places in rotation. It is his duty to make clean, even cuts, immediately on the floor of the mine, and to square up not only the corners of the rooms, but the corner of each individual cut, so that, when a room has been undercut, it will have no points of solid coal sticking out in the back of the cut to prevent the coal from being blasted with a minimum of powder. A runner, on leaving his machine at the end of his shift, when double shifts are being worked, should be careful to have all tools in their various places, so that, when the opposite partner comes on, he will know exactly where everything is to be found.

76. Duties of the Helper.—An inexperienced man first works as a helper; his duty is to shovel away cuttings, keep the mine lamps in good order and in proper position so as to reflect directly on that part of the coal face being cut, keep a sharp pick in the machine, and to keep the picks and all the tools in a special place, where they can be easily got at and will not be covered by the fine coal. It is not necessary to shovel the cuttings from the back part of an undercut, and a good helper will usually stop shoveling about 2 minutes before the undercut has been completed, and, taking his own lamp, will prepare a place for the next setting of the machine, by shoveling away any debris lying along the face of the coal, and see that the floor is cleaned up for a distance of about 9 feet from the coal face. By this time, the runner will have completed the cut and run the machine off the board. The helper then gives him his lamp from the reflector, and while the runner lifts the rear end of the running board, the helper, standing by the side of the running board next the solid face, draws the trestle along parallel to the coal face, a distance of about 5 feet; he then draws the running board along the face an equal distance, and levels up its front end while the runner adjusts the rear end. Then, placing in position the small boards used in pulling the machine from mine floor to running board, the two men each take a handle and draw the machine on to the running board. The pick is then changed, if dull; this is a place where the activity of the helper is most important, for the machine runner is absolutely idle, and any lagging on the part of the helper incurs serious loss in tonnage.

After the change of picks, the helper places the runner's lamp in the reflector, then places the dull pick on the outside end of the machine truck, and returns to the machine. He shovels away the cuttings, having first placed his lamp in the reflector. When a room has been finished, the helper closes the air valve in the pipe line near the machine, and disconnects the hose from the end of the pipe. He helps load the machine and all the accessories on the truck, and to push the loaded truck to the next place to be undercut. Before connecting the hose to the end of the pipe, he opens the air valve once or twice to clear the pipe of any coal dust or small coal that otherwise might clog the throttle valve and air ports of the machine. By this time, the runner will have the trestle and running board well in place, and a couple of minutes more time is all that is necessary to put things in shape for starting, when work proceeds as before.

77. Management.—It is essential that each machine should have its full complement of rooms on the same heading in order to avoid long moves. As a matter of economy, all sharp picks should be delivered to the runner and dull ones taken away by the coal company, and it should be looked after by the heads of departments that no machine runner loses time waiting for picks. It is equally important that the pressure in the pipe lines is not taken from the machines with which to run pumps, as this is a direct injury to the machine runner and tends to demoralize him. Where machines are to be operated on the double-shift system, it is important that men of equal productive capacity and habits be coupled together. Every mine that can afford it should have a machine boss to keep a general oversight of the machines and the runners.

78. Capacity of the Pick Machine.—On account of the many local conditions that affect the running of the machine, no definite figures can be given as to capacity. A fair average of cutting for any one machine working in rooms would be 100 lineal feet per day of 10 hours, making a cutting 6 feet deep. This in a seam 6 feet thick would make about 100 tons of coal, which would be the average output of a machine per day of 10 hours. The amount of coal that a loader can shoot down and load in a day varies, of course, with the thickness of the seam and the character of the coal, but an average for a day of 10 hours is 12 to 15 tons.

In long-wall work, as no changing of places would be required, a fair average would be 150 lineal feet, 6 feet deep, per day, making about 150 tons per machine per day.

The capacity of a pick machine for shearing depends largely on the height of the coal sheared. Working in coal of average height, eight cuts, sheared 6 feet deep, in 10 hours would be considered fair work.

TIMBERING

PROPERTIES OF MINE TIMBERS

GENERAL PRINCIPLES

INTRODUCTION

1. Necessity for Timbering.—The removal of the material underlying any stratum necessitates the temporary support of the strata above in order that the operations of mining may be continued. If this is not done, the material overlying the excavation will fall into the opening in obedience to the law of gravity. The pressure that acts on the rocks in which the excavation is made may come on any one or all of the walls about the excavation to such an extent as to cause them to break and fill the excavation. In coal mining, the top wall, or *roof*, needs the most support, although the side walls, or *ribs*, and the bottom, or *floor*, sometimes need to be protected by timbers. It is practically impossible to hold up the great weight of the superincumbent rock by any system of timbering; and were it not for the overarching of the roof material, by which the weight is thrown on the solid strata forming the sides of the excavation, it would be impossible to mine coal by any of the present methods of mining. The main object of mine timbering is to hold in place and keep from falling the loose pieces of roof rock.

2. Scope of Subject.—There is no one word in the English language that includes the various means adopted to support weak walls in mines. The term **timbering** is not sufficiently comprehensive, for masonry, concrete, and iron are used successfully for this purpose; however, for lack of a better term and because timbers are used to a greater extent than other materials, all may be treated under the general heading timbering, and subdivided for itemized description.

Timber is also used in coal mines for building brattices, stoppings, doors, regulators, air bridges, and air boxes for conducting the air through the mine workings; for chutes, platforms, gates, and batteries for handling coal after it is mined; for trackwork, covering sumps, underground stables, engine rooms, fencing off dangerous places, and various other purposes of both a temporary and a permanent nature.

3. **Timbers Used in Mines.**—The trees that grow near coal mines are the ones generally used for mine timbers. If the wood from such trees is of inferior quality and durability, it should be used only for temporary purposes or where strength is of secondary importance provided that other timber is obtainable; on the other hand, if the wood is strong and durable, it is also used where permanency is desirable. It is a mistaken idea that any wood is suitable for mine timbering, for often it will be found cheaper in the end to purchase expensive timber than to use cheap wood that must soon be replaced. It is also a mistaken idea that wood that is durable on the surface will be alike durable in every situation underground, for in some mines, it will be attacked and quickly destroyed by decay. The purpose for which the timber is to be used in the mine must always be considered; for example, room timber does not require to be so long-lived or so strong as entry timber, and some soft timber may serve the purpose here better even than a stronger and more durable timber, because it is more yielding and not so liable to break suddenly without giving the miner warning. Timbers such as spruce, tamarack, or yellow pine will resist the action of the mine air to a remarkable degree, and, therefore, are well adapted for use on airways and haulage roads.

There are two extremes where timbering fails, one where weak, brash wood is used, or wood of too small dimensions; the other where strong, durable wood is allowed to become diseased. In the first case, false economy is the cause of failure; in the second case, negligence or ignorance. It is necessary, therefore, to understand the structure of wood, the particular purposes for which it is adapted, its strength, durability, hardness, elasticity, and susceptibility to disease, and to know what methods may be adopted for its preservation.

STRUCTURE OF WOOD

4. There are two classes of trees suitable for mine timbers; namely, **coniferous trees**, or **evergreens**, and **deciduous trees**, or those whose leaves fall off in autumn. Both classes of trees are **perennial**; that is, they grow from the center outwards, adding each year a new outer layer of wood that covers the growth of the previous year.

The situation in which a tree grows has much to do with its structure; for instance, trees that grow in swampy ground have larger pores than those grown on the uplands.

Structure has much to do with the strength of wood; and as a rule a close-fibered heavy wood is stronger than one having coarse, open, porous fibers. Conifers and deciduous trees differ in the structure and character of their wood, the conifers being soft and the deciduous, generally, harder wood, although the wood of some conifers is harder than that of some deciduous trees.

In most conifers, the fibers composing the main part of the wood are all alike and their arrangement regular. On the other hand, the wood of broad-leaved trees is complex in structure and lacks the regularity of arrangement so noticeable in conifers.

5. Annual Rings.—The wood next to the bark, being of more recent growth, is porous compared with that nearer the center of the tree. The former, called the *sap wood*, contains cells that are open for the running of sap and the process of growth, while the cells of the latter, or *heart wood*, are not so open or active in the growth of the tree. Each year's growth is marked by an annular ring; and by counting these rings on the cross-section of a tree, it is possible to determine the age of the tree. The rings vary in width according to the kind of tree; and for the same kinds of trees, according to their quick or slow growth, from $\frac{1}{50}$ to $\frac{1}{8}$ inch, the latter occurring only in very thrifty trees; probably $\frac{1}{12}$ inch will be the average for thrifty trees. The rings nearest the center are generally the widest.

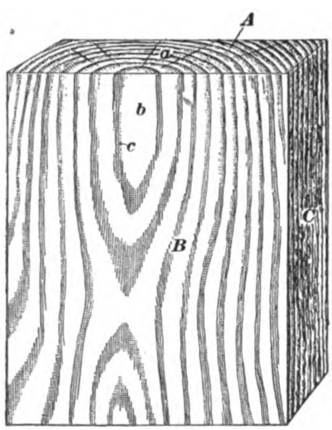


FIG. 1

Each ring is made up of an inner softer and lighter-colored part, called the *spring wood*, and an outer firmer and darker-colored portion, called the *summer wood* of the ring.

Fig. 1 shows a pine board cut lengthwise of the log so as to show a cross-section A, a tangential section B, and a radial section C; a are annual rings, b is spring wood, and c is summer wood.

Fig. 2 shows an oak board cut lengthwise of the log to show the same sections as in Fig. 1, but in the oak the darker-shaded parts b are the spring wood and the lighter parts c are the summer wood. The annual rings are at a; the great difference in appearance in the radial section C, Fig. 2, and the radial section of Fig. 1 is due to the fibers interlacing to a greater extent in oak than in pine. The tangential sections B also differ, the spring wood b and the summer wood c being less pronounced in the oak board. The lines that radiate from the center of a tree section A, Figs. 1 and 2, are called the **medullary, or pith, rays**; they are much more conspicuous in hard woods than in conifers. They appear as tapering lines on the tangential face, and as broad bands on the radial section. The wood fibers interlacing in this manner give strength to the timber across the grain.

PHYSICAL PROPERTIES OF TIMBER

6. All woods possess certain physical properties or characteristics, such as weight, durability, elasticity, hardness, etc., which adapt them to particular uses and make them more or less valuable as a mine timber.

7. Weight of Wood.—Green timber contains much sap and moisture and weighs more than seasoned or dried wood. Seasoned wood is heavier at the center and green wood is heavier on the outside. The butt wood, or that nearest the

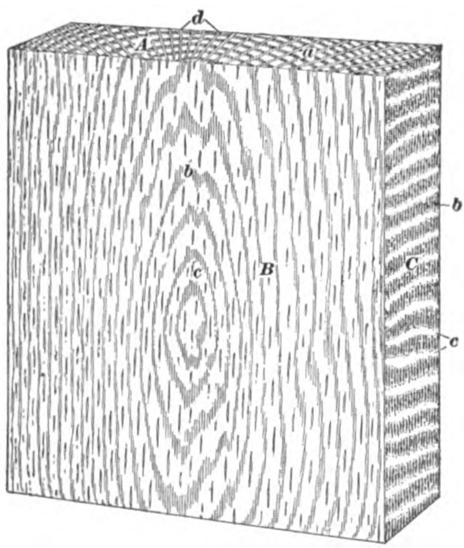


FIG. 2

ground, is usually heavier than the top wood of the same tree. In general, native woods when seasoned are not so heavy as water, weighing less than 62.5 pounds per cubic foot; in fact, few woods weigh as much as 50 pounds, and some of the pines and conifers weigh less than 30 pounds per cubic foot.

8. Seasoning Wood.—When timber loses its water, it is said to be seasoned, and consequently weighs less than in the green state, while at the same time it becomes more durable.

Timber, when dried too quickly, has a tendency to absorb moisture when again exposed and also to split or check along the grain; in drying, it will, of course, shrink. Mine timber should be well seasoned by air drying; and since the ends will dry first, they will check, but this is only local, and sometimes disappears as seasoning progresses. Timbers, if left many months in water, become water logged and sink; at the same time some of the soluble materials in the wood are leached out, without much impairing its strength. Air-dried timbers are generally used in mines, and from the time they are felled until placed in the mines they should be cared for properly.

TABLE I

APPROXIMATE WEIGHT OF KILN-DRIED WOODS

	Specific Gravity	Weight	
		Per Cubic Foot Pounds	Per 1,000 Feet B. M.* Average Pounds
Very Heavy Woods			
Hickory, oak, persimmon, beech, locust	.70 to .80	42 to 50	3,700
Heavy Woods			
Ash, elm, cherry, birch, maple, long-leaf pine, tamarack	.60 to .70	36 to 42	3,200
Medium-Weight Woods			
Pitch pine, Douglas spruce, Western hemlock	.50 to .60	30 to 36	2,700
Light Woods			
Norway and bull pine, red cedar, cypress, hemlock, spruce, fir, redwood, basswood, butternut, tulip, buckeye, yellow poplar	.40 to .50	25 to 30	2,200
Very Light Woods			
White pine, spruce, fir, white cedar, poplar	.30 to .40	18 to 25	1,800

*B. M.—Board measure.

9. Shrinkage of Wood.—Among the many peculiar features in the physics of timber is the one that wood does not shrink in the direction of the length of its fibers, but at right angles to them. This may cause cracks or checks in the direction of the length of the wood, particularly if the seasoning is carried on unevenly or so quickly that the stick does not lose its moisture uniformly. If the moisture dries out on one side of a stick quicker than on another, the stick will twist and warp.

Fig. 3 shows the effect of shrinkage; it will be noticed that the checks are lengthwise of the wood, for the reason that the longitudinal shrinkage is very little, while across the grain the shrinkage is considerable. One of the great

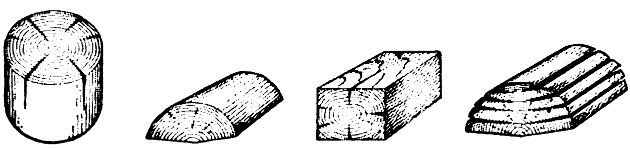


FIG. 3

troubles in wood seasoning is the difference between the amount of shrinkage along the radius and that along the rings or tangent.

Sap wood, as a rule, shrinks more than heart wood, and the harder woods shrink more unevenly and check to a greater extent than the conifers, due no doubt to the regular structure of the latter. It is not necessary to select mine timbers as woodworkers must select lumber; however, sound sticks free from shakes and, as far as possible, from checks should be chosen and inferior sticks rejected, particularly if one has to purchase the timbers. In the selection of timbers for mining purposes, their strength and enduring qualities are to be considered. Timbers to be used as props or posts have to resist crushing endwise; timbers acting as beams must resist bending and cross-breaking.

10. Time to Cut Timber.—The presence of much sap in the tree when it is cut causes the timber to decay more rapidly than it would otherwise, owing to the fermentation of the sap permitting the growth of fungi that feed on the life of the timber. In growing timber, the sap ceases to run about the middle of December and starts again about the middle of February. Timber cut, therefore, in the months of December, January, and February will contain the least sap and prove more lasting than the same timber cut at other times of the year. The work of cutting timber in winter gives employment also to farm hands during their idle season; moreover, the task of transporting timber on sleds to the mines or the railroads is a much easier one in winter than during the seasons when wagons must be used.

11. Storing Timber.—Usually, as soon as trees are felled, their bark is removed to prevent insects from injuring the wood and to prevent the sap from fermenting, during seasoning, and causing rot. The timbers should not be permitted to lie on the ground after seasoning operations are commenced, but should be placed on blocks so that they will be exposed to a circulation of air. The blocks should not be so far apart that the timbers will sag; and the timbers, if exposed to the sun, should be turned regularly, otherwise they may check or warp. Sawed timbers should be stacked up, with air spaces between the sticks; they should also be kept under sheds when seasoning and before they are taken below ground. If this is not possible, they should be stacked so that they will shed water.

The several lengths of timber should be stored together so that they can be readily obtained as required. To prevent warping and checking, the timber should not be seasoned too quickly, as is frequently the case when artificial heat is employed, or when the timber is exposed to a strong sun, especially when the circulation of air is not sufficient.

12. Durability of Mine Timber.—All wood is equally durable under certain conditions, and when submerged in water or placed where fresh, dry air can circulate about it, timber will last indefinitely. Timbers in some mines in this country have been in place over 40 years. Timbers in the Alten Mann mine in Saxony have been in place 300 years and are still in a sound condition, but this is exceptional and is only to be accounted for by their being wetted daily.

Mine timbers are generally exposed to alternate wet and dry conditions that tend to shorten the life of the timber by promoting the fermentation of the sap in the wood and the growth of fungi that feed on the wood.

13. Timber Diseases.—The term **timber diseases** refers to such natural processes as take place in timber, and in time destroy the wood. Dry rot and fungus growth are examples of natural diseases common to most timbers. Some timbers are more apt to be infested with insects and suffer from this cause more than others, owing, probably, to the nature of the wood or bark as furnishing food or nesting places for insects. Climatic conditions have much to do with this trouble; in some climates, the insects multiply rapidly and completely destroy the timber they infest. At times, the bark of the timber is completely filled with the eggs and the larvæ of insects, and must be removed in order to protect the timber from their inroads.

14. Dry Rot.—When wood is not properly seasoned, the sap is liable to ferment, especially in a dry, warm place, and **dry rot** occurs, beginning in the center of the stick and working outwards. In general appearance such a stick looks sound, but by thrusting a knife blade into it the damage is discovered. Fresh-air circulation, when the stick is away from decaying timber, is one preventive of dry rot, as in such situations the stick seasons.

15. Damp Rot.—When timber is placed in warm, moist air, **damp rot** takes place; this is the usual rot affecting mine timbers. It commences on the outside and gradually finds an entrance into the interior of the stick through some check. The destruction of a timber by damp rot is not so rapid as by dry rot and is noticeable from the fungus growth on the outside of the stick. In mines, dry rot occurs in the return airways and in poorly ventilated workings, while damp rot occurs in the intake airways and damp rooms. When fungus of the damp-rot species appears, it may be possible to save the timber and prevent the fungus reaching the heart wood by washing the stick down with lime or alum water from time to time.

16. Preservation of Timber.—The partial removal of sap will retard decay, for which reason timbers are sometimes submerged for several months, then removed and air-dried. A temperature of between 60° and 100° F. combined with moisture is favorable to decay; but mine timbers must often be placed where such conditions prevail. It may be possible, by special wood preservatives, to increase the life of timbers; but even then the sap must be either dried or removed, since wood covered with paint before being thoroughly seasoned will propagate dry rot in a warm, dry place, or damp rot in a moist, warm place. With good sound timber, creosoted joints will prolong its life, especially if the ends have been submerged in creosote a month or more. Different species of trees differ in their resistance to decay. Cedar, tamarack, and locust are more durable than pine, oak, or cypress, although in certain situations they may all have the same life. Contact with earth is particularly destructive to timber; and nearness to decaying timber is a source of disease. The principal means adopted to arrest the processes of decay and preserve timber are creosoting, salting, and charring the timber. The first two methods consist in impregnating the timber with creosote or a solution of salt so as to fill the pores. The acid acts to coagulate the albuminous matter of the sap. By this means, the pores of the wood are filled with a deposit of salt or with the coagulated albumen, which prevents the absorption of moisture and arrests the process of decay in the timber. The acid also destroys the organic life of the wood. In the third method, the charring of the ends and surface of the timber closes the pores of the wood and prevents the absorption of moisture; the charred surface of the wood will not then decay. Attempts have been made to coat mine timber with some substance, as tar, to prevent or retard its decay; in other cases, the timber has been treated with chemicals with the same end in view. The objection to the use of creosote or tar for preserving mine timbering is that they make the timber more inflammable than it would otherwise be. Timbers are sometimes treated with solutions of the chlorides or the sulphates of the various metals. When a regular plant is installed for this work, timbers are first placed in specially prepared chambers from which the air is afterwards exhausted, and then the solution for preserving the timber is forced in under pressure, the exhausting of the air having reduced the pressure on the timber and opened the cells. After the preserving material enters the chamber, it is forced into the pores of the wood in such a manner as to thoroughly saturate it.

17. Removal of Bark From Timber.—There is some difference of opinion in regard to removing the bark from timber to be used in the mine. Many do this, claiming that there is less trouble from insects destroying the timber when the bark is removed than when it is retained. The fact of the matter is that insects trouble some timbers, such as hickory, walnut, elm, etc., more than others; and are more prolific in some localities than in others. Experience indicates that it is a needless expense to strip the bark from good sound oak, hemlock, or tamarack timber that has been cut at the right time and properly seasoned.

TIMBER MEASUREMENTS

18. Timber Supplies.—The mine manager is usually able to purchase timbers and seldom has to bother with them standing. Where much timber will be needed in the operation of the mine and timber land can be secured at a reasonable cost, it will generally be found advantageous to buy such tracts and make arrangements to clear the land regularly, year by year, as the timber is required. This will make the company independent in respect to timber, and the time and manner of cutting, storing, etc. will be entirely under control. When the land has been cleared, it will, in many instances, be valuable for farm purposes and bring a price that will greatly reduce the net cost of the timber.

Where timber tracts are not owned, the timber required for the operation of the mine must be purchased as needed. For a large mine, this will generally require a regular appointed timber agent, one who is familiar with the different kinds of timber and has a thorough knowledge of the growth and properties of timber, and the requirements of mine timber. It will be necessary to make ample arrangements ahead for an adequate supply of all sizes required, so that there will be no delay in obtaining these as they are needed.

The timberman who does the felling should see to it that no good timbers are wasted and that they are cut to proper lengths. In case a small tree will answer the purpose, a large one should not be felled and its top taken, for the light wood from the top of an old tree is not so strong nor so durable as wood from a younger tree.

19. Cost of Timber.—Timber varies greatly in cost, according to locality and the price of labor. Mine timber is usually estimated at a certain price per running foot, varying from 1 cent to 4 or 5 cents per foot, according to the size of the timber and quality of the wood, and the relative supply and demand for timber in that locality. In some farming districts, where timber is plentiful, arrangements can often be made to clear the land, taking the timber in payment for the work; a specified sum may be required in some cases as a bonus.

It is usual to stipulate that a timber shall have a certain minimum diameter at its smaller end, and it is then purchased by the running foot. If a stick 8 to 12 inches in diameter at the small end costs 5 cents per running foot, a stick 16 inches in diameter will cost 9 cents; one 20 inches in diameter, 14 cents; and one 24 inches in diameter, 20 cents per linear foot. These prices are based on the increased quantity of wood in a stick, with the area of a stick 12 inches in diameter as the base, and 5 cents the base price. If timbers 12 inches in diameter can be obtained cheaper than the price named, the others should be proportionally less in price.

20. Specifications for Mine Timber.—Specifications for mine timber should state the kind and amount of timber required; the sizes, diameters, and lengths of sticks; and the time and place of delivery. The diameter of prop timber is usually specified by naming the minimum diameter of the small end of the stick. A timber contract should provide for the proper inspection of all timber by the purchaser and should give the buyer the right to reject all timber that does not fulfil the requirements of the contract. Provision should be made in the contract for the payment for timber delivered, at such times and in such amounts as will be satisfactory to the party delivering the timber, a certain specified sum being retained from each payment as guarantee of the fulfilment of the contract, such amount to be paid in full at the completion of the contract. Where timber is shipped from a distance, it should be inspected before it is loaded, in order to avoid unnecessary transportation charges.

21. Size of Mine Timber.—Sticks smaller than 6 inches in diameter are merely useful for temporary timbering or for sprags or lagging. Set timbers are often from 10 to 12 inches when squared; probably the former size is most used. Whenever round timbers are used as set timbers, they should be of such diameter as will furnish approximately the same area as a sawed stick; thus, if a 10-inch sawed stick is to be replaced by a round stick, the latter should be, approximately, $11\frac{1}{2}$ inches in diameter. [$10^2 = 100$ square inches; $(11\frac{1}{2})^2 \times .7854 = 104$ square inches.] In mine roads, set timbers are from 6 to 8 feet long, according to local practice. The caps or collars are varied in length to suit conditions, but 8 feet is a fair length. The foregoing dimensions will be varied by the mine manager and are given because they are the usual sizes for set timbers on haulage ways. Beams are used in various sizes and lengths, while props vary from mere saplings to sticks 24 inches in diameter.

LOGS REDUCED TO SQUARE TIMBER

22. The Inscribed-Square Rule.—The **inscribed-square rule** gives the largest possible theoretical result, no allowances being made for imperfections in the log or for saw cuts. The exact mathematical rule for determining the side of a square inscribed in a circle is as follows:

Rule.—*The side of the square a b, Fig. 4, is the hypotenuse of a right triangle a b c, two sides of which are radii r of the log. Hence, the side of the square is* $\sqrt{r^2 + r^2} = \sqrt{2r^2}$.

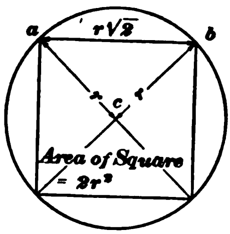


FIG. 4

Since $r = \frac{d}{2}$, that is, the diameter is twice the radius, $r^2 = \left(\frac{d}{2}\right)^2 = \frac{d^2}{4}$. Therefore, $2r^2 = \frac{d^2}{2}$ and the side of a square inscribed in a circle equals $\sqrt{\frac{d^2}{2}}$. The area of the inscribed square will therefore be equal to the side squared, or

$$(\sqrt{2r^2})^2 = 2r^2 = \left(\sqrt{\frac{d^2}{2}}\right)^2 = \frac{d^2}{2}$$

EXAMPLE.—The circumference of a log at its middle length is 37.7 inches; according to the exact mathematical rule for determining an inscribed square in a circle, what will be the area of the stick when squared?

SOLUTION.—Since 3.1416 × the diameter = the circumference, 37.7 ÷ 3.1416 = 12, or the diameter of the log. Then, according to the rule, $\sqrt{\frac{d^2}{2}} = \sqrt{\frac{144}{2}} = \sqrt{72} = 8.48$ in., as the side of the inscribed square, and 8.48 × 8.48 = 72, the area, in square inches. Ans.

Again, since the radius is half the diameter, the radius squared multiplied by 2 gives the area, or 72 sq. in.

The diameter or circumference of a log at the middle of its length is often taken in such calculations, though to be absolutely correct the smaller end of the log should be measured.

The circumference at the middle length of the log may be measured and the area and radius calculated from this measurement, the two ends of the log may be measured and the middle section calculated as one-half the sum of the two ends. Then, if the area of one end of a log is 140 square inches and that of the other end 120 square inches, the area of the center section is $\frac{120 + 140}{2} = 130$ square inches.

It is impossible to cut from a log a square timber of the theoretical size owing to imperfection in the timber, differences in diameter of the two ends of the log, and waste in sawing or hewing. Hence, timbermen have a number of approximate rules for estimating the size of square timber obtainable from a given log. The following are a few of the most frequently used of these rules:

23. The Two-Thirds Rule.—In the **two-thirds rule** for determining the amount of square timber contained in logs, allowance is made for the waste that occurs, owing to the fact that logs are seldom perfectly round and straight. The diameter of the log is taken at the middle of its length, or the diameters of the two ends of the log are added together and divided by 2 to obtain the average diameter. To allow for slabs in cutting, only two-thirds of the diameter is taken as the width of the square piece that may be hewn or sawed out of the log.

EXAMPLE 1.—The circumference of a log at the middle of its length is 37.7 inches; according to the two-thirds rule, what will be the area of the stick when squared?

SOLUTION.—Since 3.1416 × diameter = the circumference, 37.7 ÷ 3.1416 = 12, or the diameter of the log. According to the rule, $\frac{12 \times 2}{3} = 8$ in. as one edge of the stick; hence, the area is

$$8 \times 8 = 64 \text{ sq. in.} \quad \text{Ans.}$$

EXAMPLE 2.—The diameters of a log at its ends are 12 and 16 inches, respectively; what will be the width of a square stick cut from such a log, if the two-thirds rule is used?

SOLUTION.—The average diameter is $\frac{12 + 16}{2} = 14$ in.; then, by the rule,

$$\frac{14 \times 2}{3} = 9\tfrac{1}{3} \text{ in. wide.} \quad \text{Ans.}$$

24. Quarter-Girth Rule.—The formula $A = 1.97\, r^2$ gives very nearly the exact area of a square piece that can be cut from a log whose diameter at the middle of its length is r. The bark should be removed from the log before it is measured. This formula is derived as follows: The circumference of a log is measured at its middle length with a tape and equals $2\pi r$. One-fourth of this quantity is squared, that is,

$$\left(\frac{2\pi r}{4}\right)^2 = \frac{4\pi^2 r^2}{16}; \text{ four-fifths of this is, } \frac{4}{5}\left(\frac{4\pi^2 r^2}{16}\right)$$

$$= \frac{\pi^2 r^2}{5} = 1.97\, r^2$$

Example.—If the circumference of a stick measured at a center point is 37.7 inches, what will be the area of a stick sawed from such a log according to the quarter-girth rule?

Solution.—The diameter of this log is $37.7 \div 3.1416 = 12$. $r = 12 \div 2 = 6$.

$$A = 1.97 \times 6^2 = 70.92 \text{ sq. in. Ans.}$$

CUBICAL CONTENTS OF A TIMBER

25. For all practical purposes, the cubic feet in a stick of timber may be obtained by finding the area of its middle cross-section and multiplying this by its length. The area of its middle cross-section may be found from its perimeter at its middle length, or by taking the diameters at each end and dividing their sum by two, for an average diameter. If the length is in feet and the diameter in inches, divide the result obtained above by 144; and if all dimensions are in inches, divide the result by 1,728.

26. Molesworth's Rule.—All dimensions being given in feet, the following rule is adopted by some for finding the cubic feet in a log:

Rule.—*Add together the squares of the diameters of the greater and lesser ends, and the product of the two diameters; multiply the sum by .7854 and this product by one-third the length of the log.*

Example.—The diameters of a log at its ends are 2 feet and 1.4 feet respectively, and its length is 15 feet; what number of cubic feet does it contain?

Solution.— $2^2 + 1.4^2 + (2 \times 1.4) = 8.76$, and $8.76 \times .7854 \times \frac{15}{3} = 34.40$ cu. ft. Ans.

27. When the length is in feet and the diameters in inches, proceed as in Art. **26**, and divide the result by 144.

EXAMPLE 1.—The diameters of a log are 24 and 18 inches, respectively, at its ends, its length being 15 feet; what will be its volume, in cubic feet?

SOLUTION.— $[24^2 + 18^2 + (24 \times 18) \times .7854 \times 5] \div 144 = 36.32$ cu. ft. Ans.

When the dimensions are in inches, proceed according to the rule in Art. **26**, and divide the answer by 1,728.

EXAMPLE 2.—The diameters of a log are 20 and 15 inches, respectively, at its ends, its length being 144 inches; what will be its volume, in cubic feet?

SOLUTION.— $[20^2 + 15^2 + (20 \times 15) \times .7854 \times \frac{144}{3}] \div 1{,}728 = 20.18$ cu. ft. Ans.

28. Board Measure.—Lumber or framing timber is usually sold by board measure. One foot, board measure, is $\frac{1}{12}$ cubic foot; that is, it is 1 foot square and 1 inch thick; hence, to reduce cubic feet to board measure, multiply by 12.

Rule.—*To express lumber in terms of board measure, multiply together the thickness in inches, the width in inches, and the length in feet, and divide the product by 12; the result will be the contents in board feet.*

A board 1 inch thick, 12 inches wide, and 12 feet long will contain $\frac{1 \times 12 \times 12}{12} = 12$ board feet; a board 6 inches wide, 1 inch thick, and 10 feet long will contain $\frac{1 \times 6 \times 10}{12} = 5$ board feet. Boards that are more than 1 inch thick are termed **planks** and are sold by board measure; thus, a plank $1\frac{1}{2}$ inches thick, 10 inches wide, and 12 feet long will contain $\frac{3 \times 10 \times 12}{2 \times 12} = 15$ board feet.

EXAMPLE.—How many feet, board measure, are there in sixteen joists 3×4 inches in section and 16 feet long?

SOLUTION.— $\frac{16 \times 3 \times 4 \times 16}{12} = 256$ board ft. Ans.

In the specifications for buildings and the purchase of lumber, board measure is of importance in determining the cost. Planks for lagging or caps are also purchased by board measure.

STRENGTH OF TIMBER

29. All calculations for determining the strength of timber consider the material as a bundle of parallel fibers; such fibers, according to the nature of the wood, have a definite strength which is determined by experiment.

30. Stress.—The intensity of the internal resistance of the timber due to a load is called **stress.** The combined strength of the fibers forming a stick of timber, estimated for a unit sectional area, is called the **fiber stress;** it is the load per unit of sectional area, and is usually stated in pounds per square inch of cross-section.

The **ultimate stress, or ultimate load,** is the stress or load at the moment when the rupture of the fibers begins; it indicates the limit of strength of the material and is often called the *breaking load* or *breaking strength.*

The **elastic limit** is that point of loading or that stress that marks the limit of the elasticity of the material; or, in other words, the point of loading at which the load or stress causes permanent deformity in the material.

The **safe load, or proper working load or stress,** is a load or stress within the elastic limit of the material; that is, that does not produce permanent deformation.

31. Factor of Safety.—The **factor of safety** is usually understood as being the ratio of the load adopted as the greatest safe load or stress to the ultimate load, but the inverse of this ratio is also sometimes called the factor of safety. The factor of safety is thus expressed as a fraction or as a whole number; for example, the factor of safety may be expressed as 5 or $\frac{1}{5}$, signifying, in either case, that the adopted greatest safe load is one-fifth of the ultimate, or breaking, load.

32. Action of a Load.—A load supported by a stick of timber may act in a direction parallel to or across the fibers; when acting parallel to the fibers, the load produces a **longitudinal stress.** A load acting across the fibers is called a **transverse load.** A transverse load may produce a longitudinal stress in the fibers similar to a load acting parallel to the fibers; or it may produce no longitudinal stress, but act simply as a force to cut the fibers in a plane more or less perpendicular to their length; this is called **shearing.**

A stick supporting a load that acts parallel to its fibers is called a **post or strut,** while a stick supporting a load that acts across its fibers is called a **beam.**

33. Compression and Elongation.—A force acting parallel to the fibers produces compression or elongation in the fibers, according to the manner of its application. A load supported by a post produces compression, which tends to shorten the length of the fibers of the post. If the load is suspended from the end of a rod, it tends to lengthen the fibers.

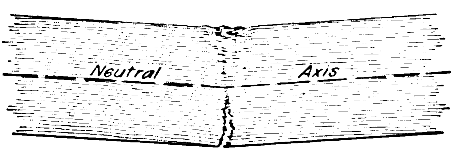


FIG. 5

The fibers of a beam supporting a transverse load, when bending occurs, are subject to both compression and elongation. The first effect of a transverse load is to bend the beam, which lengthens all the fibers on the convex side and shortens all the fibers on the concave side of the beam, Fig. 5. The fiber at or near the center, which is neither lengthened nor shortened, is called the **neutral axis.** The neutral axis is generally assumed to pass through the center of gravity of the cross-section of the stick.

34. Elasticity of Timber.—By the **elasticity of timber** is meant the power of the fibers to assume their original position after being compressed or extended. The degree of elasticity is indicated by the quickness with which the fibers regain their original position when the load is taken off. Any change in the length or relative position of the fibers of the timber due to a load is called **deformation.** If the fibers do not resume their original position when relieved of the load, it is because the deformation has exceeded the limit of elasticity of the material, and the load is then said to have produced **permanent deformation.**

Timber is permanently weakened by being loaded beyond its elastic limit. Deformity usually occurs before rupture takes place, excepting sometimes in a brittle material.

35. Modulus (Coefficient) of Elasticity.—Within the elastic limit of the material, the amount of deformation caused by a load is always proportional to the unit stress or fiber stress; that is to say, when the compression or extension of the fibers is not so great but that they will return to their original length when the load is removed, the amount of compression or extension is proportional to the unit load. The ratio of the unit load or fiber stress to the compression or extension it produces per unit of length, in any given material, is called the **modulus of elasticity,** or sometimes the **coefficient of elasticity.** The value of the modulus of elasticity is given by the following formula:

$$E = \frac{W}{a} \div \frac{l}{L} = \frac{\text{fiber stress}}{\text{elongation per unit of length}}$$

in which E = modulus of elasticity, in pounds per square inch;
W = total load supported, in pounds;
a = sectional area of timber, in square inches;
l = amount of elongation, in inches;
L = length of timber, in inches.

The total load W divided by the sectional area a gives the unit load or fiber stress produced in the material; and the amount of elongation l divided by the length of the stick L gives the elongation per unit of length.

To make the use of this formula clear, suppose that a post having a sectional area of 30 square inches is supporting a load of 30 tons, the unit or fiber stress produced by this load is $\frac{30 \text{ tons}}{30 \text{ square inches}} = 1$ ton of 2,000 pounds per square inch; and suppose, further, that this load produces a compression of $\frac{1}{800}$ of the length of the post; that is to say, if the post is 100 inches long, the compression produced by this load is $\frac{1}{8}$ inch. The modulus of elasticity of the material is then,

$$E = \frac{2{,}000}{\frac{1}{800}} = 1{,}600{,}000$$

If the modulus of elasticity of the material is known, the compression, or elongation, due to any load may be found, if the stress due to the load does not exceed the elastic limit of the material.

POST TIMBER

36. Post timber may fail in one of two ways: by the crushing or furring of the fibers at the end of the post; by the bending and breaking of the post. In general, in thin seams, the length of the post is small and the diameter relatively large; while in thick seams, the length of the post is large and the diameter relatively small. In the former case, the posts are short and thick and will crush at the ends before they will bend. In the latter case, the posts are long and slim and will bend and break before being crushed at the ends.

37. Crushing Load.—Since the load on a post acts parallel to the fibers, the unit load or fiber stress is found by dividing the load supported by the sectional area of the post. Or, if the ultimate unit strength of the material is known, the breaking load of the post or strut will be found by multiplying the ultimate unit strength by the sectional area. When the load produces compression, the ultimate fiber stress is called the **crushing strength** of the material. When the load produces elongation, the ultimate stress is called the **tensile strength** of the material. The least load producing crushing is expressed by the following formula:

$$W_c = S_c \times a$$

in which W_c = least load that will crush post, in pounds;
S_c = crushing strength of timber, in pounds per square inch;
a = sectional area of post, in square inches $= .7854\ d^2$;
d = diameter of cross-section of post.

EXAMPLE.—Find the least load that will crush the ends of a post 6 inches in diameter and of such length that the post will crush before it will bend, assuming the timber has a crushing strength of 8,000 pounds per square inch.

SOLUTION.—Substituting the given values in the formula,

$$W_c = \frac{8{,}000(.7854 \times 6^2)}{2{,}000} = 113+ \text{T. Ans.}$$

38. Bending Load.—The bending load on a post is not determined so simply as the load producing crushing; it is expressed by the following formula:

$$W_b = EI\left(\frac{\pi}{l}\right)^2$$

in which W_b = least load that will bend the post, in pounds;
E = modulus of elasticity of timber;
I = moment of inertia of cross-section of post, referred to neutral axis through center of gravity of section;
l = length of post.

A post may be square, round, or rectangular, or its cross-section may have any irregular shape. The strength of a post to resist bending depends much on the shape of its cross-section. A round post will bend with equal readiness in any direction, since its cross-section is a circle; a square post will bend most readily in a direction perpendicular to one of its sides; a rectangular post will bend most readily in a direction perpendicular to its longest side; a post of irregular cross-section will bend in any direction, depending on the massing of the material with respect to a longitudinal axis.

39. The **moment of inertia** of a cross-section of any shape is an expression used in determining the resistance of a stick to bending. The moments of inertia of a circle, square, and rectangle referred in each case to an axis $x x$ passing through the center of gravity of the figure are given in Fig. 6.

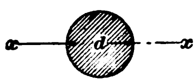
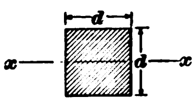
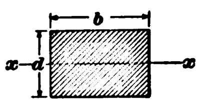
Shape of Cross-Section	Moment of Inertia, I
Circle 	$\frac{\pi d^4}{64}$
Square 	$\frac{d^4}{12}$
Rectangle 	$\frac{b d^3}{12}$

FIG. 6

In these expressions, d is the diameter of a circle, the side of a square, or that side of a rectangle that is perpendicular to the neutral axis $x x$ of the cross-section, while b is the other side of the rectangle parallel to the neutral axis.

40. The values for the strength of timber, as published by different authorities, vary widely; due, in great part, to the different conditions under which the timbers were tested. For instance, some of the tests have been made on small, perfectly clear, and thoroughly dried sticks; others have been made on large commercial timbers containing knots, crooked grained, and in a green condition. It is well known that thoroughly kiln-dried timber is several times as strong and as stiff as the same timber when green. It is also well known that large sticks of merchantable timber containing knots and crooked grains are usually only about one-half as strong as small, clear sticks. The rate of growth of the timber also has a very appreciable effect on its strength.

In using values for the strength of timber, the conditions under which the tests were made and on which the values are based must be considered. Unfortunately, there are no comprehensive tests of timbers under the conditions in which they are used in underground mine work; and in using strength values for mine timber, a factor of safety varying from 3 to 10 must be used, depending largely on the judgment of the person making the calculation.

41. Table II gives the kinds of timber most commonly used in mining, the strength under crushing, under tension, under shear, and the modulus of elasticity. The values given are taken, as far as possible, from the publications of the Forestry Division of the United States Department of Agriculture, Washington, D. C. The values of the crushing strengths are obtained from tests on small sticks of fairly clear material, thoroughly dried. As the greater part of the timber used for structural purposes about mines and for supporting the roof never reaches the degree of seasoning of the tested specimens, the values given are higher than those that would be found by similar tests made on mine timbers. These values must therefore be modified by the use of suitable factors of safety. The values for tension and shearing are those adopted by the Committee on Strength of Bridge and Trestle Timbers of the Association of Railway Superintendents of Bridges and Buildings, in its fifth annual convention, held in New Orleans, October, 1895. These values are also based largely on the reports of the Forestry Division of the United States Department of Agriculture.

EXAMPLE 1.—What is the least load that will bend a Northern spruce post 6 inches in diameter and 6 feet long?

SOLUTION.—Taking the modulus of elasticity for Northern spruce as $E = 1{,}470{,}000$ and substituting this value and the values for the moment of inertia, and for the length, l, in the formula in Art. **38**, the least load producing bending in this case is

$$W_b = 1{,}470{,}000 \left(\frac{\pi\, 6^4}{64}\right)\left(\frac{\pi}{6 \times 12}\right)^2 \frac{1}{2{,}000} = 89.02 \text{ T. Ans.}$$

Assuming a factor of safety of 3, the safe load on this post would be $\frac{89.02}{3} = 29.67$ T. Ans.

EXAMPLE 2.—What is the safe bending load on a Northern spruce square post measuring 6 inches on each side and 6 feet in length, assuming a factor of safety of 3?

SOLUTION.—Taking the same modulus of elasticity, $E = 1{,}470{,}000$, and substituting it, together with the value for the moment of inertia of a square $\left(\frac{d^4}{12}\right)$, and the value for l, in the formula in Art. **38**, the least load producing bending is

$$W_b = \frac{1{,}470{,}000}{3}\left(\frac{6^4}{12}\right)\left(\frac{\pi}{6 \times 12}\right)^2 \frac{1}{2{,}000} = 50.38 \text{ T. Ans.}$$

EXAMPLE 3.—What is the safe bending load for a Northern spruce post having a rectangular cross-section and measuring 6 inches on one side and 8 inches on the other, and 6 feet long, using a factor of safety of 3?

SOLUTION.—This post will bend in the direction of its least thickness, making the short side perpendicular to the neutral axis and the long side parallel to that axis; hence, in this case, $b = 8$, $d = 6$, $l = 6 \times 12$. Assuming the same modulus of elasticity as before, and substituting these values in the formula in Art. **38**, the least load producing bending in this case is

$$W_b = 1{,}470{,}000\left(\frac{8 \times 6^3}{12}\right)\left(\frac{\pi}{6 \times 12}\right)^2 \frac{1}{2{,}000} = 201.51 \text{ T.}$$

$$\frac{201.51}{3} = 67.17 \text{ T. Ans.}$$

42. In post timbering, it is desirable to determine such a diameter of the post relative to its length that the timber will present the same resistance to crushing as to bending. The length of the post is practically determined by the thickness of the seam or the height of the opening. The following rule for determining the diameter of the post relative to its length is in common use:

Rule.—*In order that post timber shall present equal resistance to crushing and bending, the diameter of the post, in inches, should be equal to its length, in feet; that is to say, the diameter of the post should be one-twelfth of its length.*

In considering sawed timber, it is common practice to regard a column as having a length equal to fifteen times its

TABLE II

STRENGTH OF TIMBER

Species	Crushing Strength, Parallel to Fiber, of Small, Clear, Dry Sticks Containing 12 Per Cent. of Moisture Pounds Per Square Inch	Modulus of Elasticity, in Bending Pounds Per Square Inch	Tensile Strength With the Grain Pounds Per Square Inch	Shearing Strength Across the Grain Pounds Per Square Inch
American ash	7,200[a]	1,640,000[a]	17,000[f]	6,280[f]
Birch	8,000[f]	1,645,000[f]	15,000[f]	5,600[f]
Chestnut	5,300[b]	1,140,000[b]	9,000[e]	1,500[e]
Cedar, white	5,200[a]	910,000[a]	8,000[e]	1,500[e]
Hemlock, Western	7,900[b]	1,640,000[b]	6,000[e]	2,500[e]
Hemlock	5,700	1,680,000		
Hickory, American	9,500[a]	2,390,000[a]	19,600	6,000
Oak, white	8,500[a]	2,090,000[a]	10,000[e]	4,000[e]
Oak, red	7,200[a]	1,970,000[a]	10,250[f]	
Oak, black or yellow	7,300[a]	1,740,000[a]	10,000[f]	
Oak, live	10,400[c]	1,851,000[c]		8,480[f]
Pine, Southern long-leaved	8,000[a]	2,070,000[a]	12,000[e]	5,000[e]
Pine, North Carolina Loblolly	7,400[a]	2,050,000[a]	13,000[f]	
Pine, white	5,400[a]	1,390,000[a]	7,000[e]	2,000[e]
Pine, Southern spruce	7,300[a]	1,640,000[a]	8,000[e]	3,000[e]
Pine, Oregon	8,340[b]	1,904,000[b]	12,000[e]	
Pine, Northern or short-leaved yellow	6,000[c]	1,200,000[c]	9,000[f]	4,000[e]
Red gum	5,600[b]	1,550,000[b]		
Spruce, Northern	5,600[b]	1,470,000[b]	11,000[f]	3,250[f]
Walnut, black	7,500	1,306,000[b]	10,500[f]	4,700[f]

a Taken from reports of Division of Forestry, United States Agricultural Department, Washington, D. C.
b Taken from reports of Forest Service, United States Agricultural Department, Washington, D. C.
c Thurston.
e Association of Railway Superintendents of Bridges and Buildings.
f Pocketbook of Pencoyd Iron Works based on United States Forestry reports.

diameter as presenting an equal resistance to bending and crushing; but for round timber the rule just given is the safer one, as it agrees quite closely with the theoretical considerations, as expressed by the formulas given in Arts. **37** and **38**, as shown by the following demonstration:

If, in the expression for the bending load, $W_b = EI\left(\frac{\pi}{l}\right)^2$, the moment of inertia of a circle, as given in Art. **39**, is substituted.

$$W_b = E\left(\frac{\pi d^4}{64}\right)\left(\frac{\pi}{l}\right)^2$$

if, then, this expression is placed equal to the expression for the crushing load, as given in Art. **37**,

$$W_c = S_c\,(.7854\,d^2)$$

$$E\left(\frac{\pi d^4}{64}\right)\left(\frac{\pi}{l}\right)^2 = S_c\,(.7854\,d^2)$$

Solving the equation for $\frac{d}{l}$,

$$\frac{d}{l} = 1.273\sqrt{\frac{S_c}{E}}$$

To illustrate the use of this formula, calculate the ratio between the diameter and length of a post of Northern spruce timber such that the post will present equal resistance to crushing and bending. Substituting in the formula the values given in Table II, for the crushing strength and modulus of elasticity of Northern spruce timber, the ratio of the diameter to the length of the post to fulfil the required conditions is as follows:

$$\frac{d}{l} = 1.273\sqrt{\frac{5,600}{147,000}} = .0786$$

In like manner, calculating the ratio of the diameter to the length of post timber for the woods given in Table II, the values given in Table III are obtained.

TABLE III

Wood	Ratio	Wood	Ratio
Ash	.0843	Black or yellow oak .	.0825
Birch	.0888	White oak.	.0812
Cedar (white)	.0962	Live oak	.0954
Chestnut	.0868	Yellow pine (Southern	
Oregon pine	.0884	long leaved)	.0791
Hemlock	.0742	White pine	.0794
Hickory (American)		Northern spruce . . .	.0786
average	.0803	Spruce pine (Southern)	.0849
Red oak	.0770	Black walnut	.0965

Expressing the diameter of the post as a percentage of its length, for the timbers in Table III, this percentage ranges from a minimum of 7.42 per cent. in hemlock to a maximum of 9.65 per cent. in black walnut; and the average value of the ratios for the timbers in Table III is .0846, or the average ratio of the diameter to the length of posts for all the kinds of timber in the table is about $\frac{1}{12}$.

43. Arching of Roof Material.—As was explained in *Methods of Working*, and as illustrated in Figs. 7 and 8, the

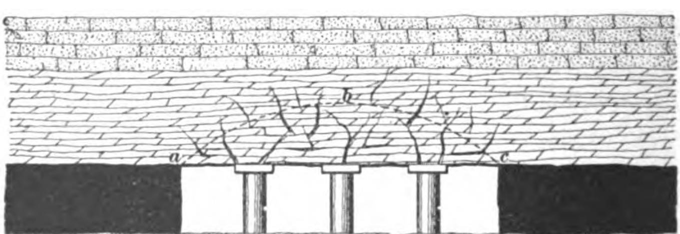


FIG. 7

removal of the coal from a portion of seam results in the crevicing of the overlying strata. That portion of the cover immediately above the opening is broken into a mass of fragments varying in size and shape according to the character of the material. Sandstone, limestone, conglomerate, etc. break in large, irregular fragments, while shales, slates, etc. break in slabs and present a foliated condition. The loosened fragments in each case bind and wedge each other as they attempt to fall, and there is formed a natural arch spanning the opening, as indicated by the dotted lines *acb* in each figure. The height of this arch varies with the character of the overlying rock, being higher as the fragments are larger and more irregular in shape, Fig. 8. Where

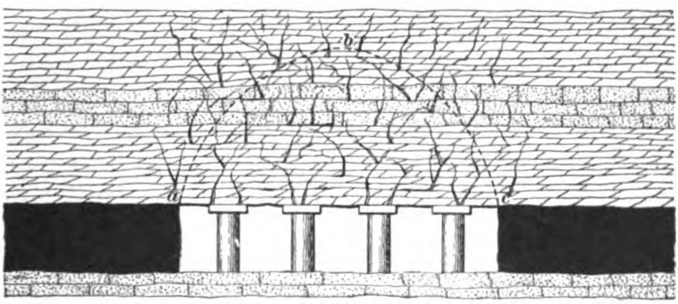


FIG. 8

the material breaks in slabs or is foliated as is the case with shales and slates, the arch is comparatively low and flat, as shown in Fig. 7.

Before the size of timber required to support this loosened material can be calculated, it is necessary to arrive at some approximation of the height of the arch. The height depends on the character of the material forming the strata, and as it cannot be determined, it will probably be a safe approximation to estimate the height of the arch as equal to the span, or the width of the opening.

44. The Load on Room Timbers.—Assuming, under proper conditions of mining, that the general weight of the overlying strata rests on the pillars separating the openings in the seam, and that the underweight, or weight of the loosened arch material only, rests on the timbers; and assuming, also, that the height of the natural arch formed in the roof above each opening is equal to the width of the opening, it is possible to estimate the load that will rest on the timbers;

then, knowing the load on each timber, the diameter of the post necessary to support this weight can be calculated by the formula,

$$d = \sqrt{\frac{C W_c}{.7854 S_c}}$$

in which d = diameter of post;
C = factor of safety;
W_c = weight on each post;
S_c = crushing strength of given timber per square inch.

For example, assuming the weight of the material forming the roof strata to be 160 pounds per cubic foot, that the posts are set 4 feet, center to center each way, and that the height of the overarching material is equal to the width of the opening, 30 feet, the weight of material resting on a single post is then

$$\frac{160 (4 \times 4 \times 30)}{2{,}000} = 38.4 \text{ tons.}$$

The crushing strength, S_c, of the timber is taken from Table II, and a factor of safety is chosen, depending on the judgment of the person making the calculation.

Example.—Calculate the diameter of posts required to timber an opening 30 feet wide under a sand-rock roof weighing 160 pounds per cubic foot, when hemlock posts are set 5 feet apart, and a factor of safety of 2 is used, assuming that the roof is broken for 30 feet above the top of the post.

Solution.—The weight resting on each post is $W_c = 160 (5 \times 5 \times 30) = 120{,}000$ lb. Then, using hemlock timber having a crushing strength of 5,700 lb. per sq. in., the diameter of each post is

$$d = \sqrt{\frac{2 \times 120{,}000}{.7854 \times 5{,}700}} = 7.3 \text{ in. Ans.}$$

An 8-in. prop would be used.

45. Since it is seldom or never possible to determine the height of the arch of loose rock, the size of timbers and their distance apart must usually be determined by the practical experience of the timberman.

Since the length of post timber is practically determined by the thickness of the seam or height of opening, greater economy is obtained in the use of timber when the diameter of the post is proportioned to its length, according to the rule given in Art. **42**, so that the post shall present equal resistance to crushing and bending. The distance between the post is then made such that the load on each is proportioned to its diameter.

EXAMPLE.—Find the distance apart of hemlock posts in a 6-foot seam overlaid with sand rock or limestone when the opening is 30 feet wide, using a factor of safety of 2.

SOLUTION.—Assuming, in this case, the length of the post equal to the thickness of the seam, and making the diameter of the post, in inches, equal to its length, in feet, according to the rule given in Art. **42**, the diameter of the post in this case is 6 in. Taking one-half of the crushing strength of hemlock given in Table II, the safe load each post will support in this case is $W = \frac{5,700}{2}(.7854 \times 6^2) = 80,582$ lb.

Assuming the height of the overarching roof equal to the width of the opening, the weight supported by the timbers is, $W = 160 \times 30 = 4,800$ lb. per sq. ft.

The area of roof that each post will support with safety is then, $80,582 \div 4,800 = 16.79$ sq. ft., and the distance of the posts, center to center, in systematic timbering is then, $\sqrt{16.79} = 4.09$, say 4 ft. Ans.

In speaking of the diameter of a post, the diameter at the small end is always meant, since the post is no stronger, so far as crushing is concerned, than the resistance offered by the small end.

BEAMS

46. Strength of Beams.—In the case of a beam, the load acts across the fibers and the longitudinal stresses producing compression and elongation in the fibers of the beam are not determined so simply as in the case of posts. In considering beams, it is customary to determine the breaking load of the beam from the ultimate tensile strength of fiber stress of the material, thus considering only those fibers in extension. The least load that will break a beam fixed at one end and loaded at the other, or a cantilever beam loaded at its extremity, Fig. 9, is determined by the formula,

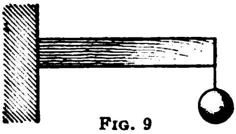


FIG. 9

$$W = \frac{2fI}{ld} \qquad (1)$$

in which

W = load supported by beam, in pounds;
f = fiber stress of material, in pounds per square inch;
I = moment of inertia of cross-section of beam;
l = length of beam, in inches;
d = depth of beam, in inches.

For a cantilever beam uniformly loaded, Fig. 10, multiply the result obtained in formula **1** by 2.

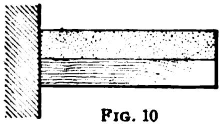


FIG. 10

$$W = \frac{4fI}{ld} \qquad (2)$$

For a beam supported at both ends and loaded at the center, Fig. 11, multiply the result obtained in formula **1** by 4.

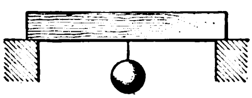


FIG. 11

$$W = \frac{8fI}{ld} \qquad (3)$$

For a beam supported at both ends and uniformly loaded, Fig. 12, multiply the result obtained in formula **1** by 8.

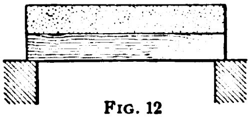


FIG. 12

$$W = \frac{16fI}{ld} \qquad (4)$$

For a beam fixed at both ends and loaded at the center, Fig. 13, multiply the result obtained in formula **1** by 8.

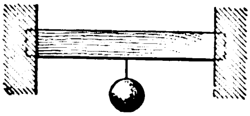


FIG. 13

$$W = \frac{16fI}{ld} \qquad (5)$$

For a beam fixed at both ends and uniformly loaded, Fig. 14, multiply the result obtained in formula **1** by 16.

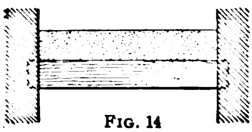


FIG. 14

$$W = \frac{32fI}{ld} \qquad (6)$$

EXAMPLE 1.—What is the safe center load for a white-oak collar beam 8 inches in diameter and measuring 8 feet between the notches or points of support, assuming, from Table II, for the ultimate fiber stress $f = 10{,}000$ pounds per square inch, and a factor of safety of 3?

SOLUTION.—Substituting in formula **3**, the values given above, and for I the moment of inertia of a circle referred to an axis through its center $\left(\frac{\pi d^4}{64}\right)$, and multiplying by 4, for a beam supported at both ends and loaded at the center, the least breaking load is

$$W = 4\left(\frac{2 \times 10{,}000}{8 \times 12 \times 8}\right)\left(\frac{\pi 8^4}{64} \times \frac{1}{3}\right) = 6{,}981+ \text{ lb., about } 3.49 \text{ T.} \quad \text{Ans.}$$

EXAMPLE 2.—What load uniformly distributed will this collar beam support?

SOLUTION.—Assuming the same conditions in other respects, a uniformly distributed load that will just break a beam is always double the least center breaking load; hence, in this case, the beam will safely support a load of 6.98 T. uniformly distributed. Ans.

47. Relative Strength of Round and Square Beams. For equal strength, the side of a square beam is but five-sixths of the diameter of a round one. If the formula for a beam given in Art. **46** is written, first for square and then for round timber, by substituting for I the moment of inertia of a square and a circle, respectively, then

$$\text{Square timber, } W = \frac{2f}{ld} \times \frac{d^4}{12} = \frac{fd^3}{6l}$$

$$\text{Round timber, } W = \frac{2f}{ld} \times \frac{\pi d^4}{64} = \frac{\pi fd^3}{32l}$$

Then, to find the side x of a square timber that will carry the same load as a round timber whose diameter is d, the length l being the same in each case, place the values of W given by the above formulas equal; thus, $\frac{fx^3}{6l} = \frac{\pi fd^3}{32l}$. By canceling equal factors and reducing, $x = .838\,d$. That is to say, the side of a square beam of equal span and strength is .83, or five-sixths, of the diameter of a round beam. In other words, a 5-inch square beam will carry the same load as a 6-inch round beam, and a 10-inch square beam will carry the same load as a 12-inch round beam. Since, however, a beam 5 inches square must be cut from a 7-inch tree, and a beam 10 inches square from a 14-inch tree, there will be no saving but rather a waste of material in using square timber on this account. It is, however, often necessary to know the relative strength of beams of different cross-sections, and this can readily be estimated by substituting the moment of inertia of the beams as above in the formula.

48. Relation of the Diameter of a Beam to Its Strength.—Other things being equal, the strength of a cross-beam or collar varies as the cube of the diameter; hence, the strengths of two beams of the same length, but different diameters, are proportional to the cubes of their diameters. In other words, the relative strength of two beams is equal to the cube of the ratio between the diameters of the two beams. Thus, for the same span, a 12-inch beam will carry eight times the load of a 6-inch beam. ($\frac{12}{6} = 2$; $2^3 = 8$.) Letting W_1 and W_2 represent the strengths of two beams of the same length and 6 and 8 inches in diameter, respectively,

$$W_1 : W_2 = (6)^3 : (8)^3.$$

$$\frac{W_1}{W_2} = \left(\frac{6}{8}\right)^3 = \left(\frac{3}{4}\right)^3 = \frac{27}{64}$$

That is to say, for every 27 pounds carried by the 6-inch beam, an 8-inch beam of the same span will carry 64 pounds.

Two pieces of square timber may be similarly compared, the strength of a square timber varying as the cube of the side.

EXAMPLE.—If an 8-inch round timber of a given span will safely carry a load of 5 tons, what load will a similar 12-inch beam, with the same span, support?

SOLUTION.—Calling the required load x, then $x : 5 = 12^3 : 8^3$. $\frac{x}{5} = \left(\frac{12}{8}\right)^3 = \left(\frac{3}{2}\right)^3 = \frac{27}{8}$; and,

$$x = 5 \times \tfrac{27}{8} = 16.87, \text{ or } 17 \text{ T., approximately. Ans.}$$

49. Relation of Length of Span to Strength of Beam.—The strength of a cross-beam or collar varies inversely as the length of the span; hence, two beams otherwise equal vary in strength inversely as their lengths. In other words, the ratio between the strengths of two beams, equal and similar in cross-section, is equal to the inverse ratio of their lengths. Thus, other dimensions being equal and the beams similarly supported and loaded, an 8-foot stick will carry twice the load of a 16-foot stick.

EXAMPLE.—If an 8-foot cross-beam or collar will safely support a load of 10 tons, what load will a similar stick of the same sectional size and 12 feet long support?

SOLUTION.—Calling the required load x, then $x : 10 = 8 : 12$. $\frac{x}{10} = \frac{8}{12} = \frac{2}{3}$; and,

$$x = 10 \times \tfrac{2}{3} = 6\tfrac{2}{3} \text{ T. Ans.}$$

50. Relation of Other Dimensions to Length of a Cross-Beam.—For the same total load on the beam, the cube of the diameter of a round beam varies as the length; that is, for the same total load on the beam, the cube of the ratio between the diameters of two beams is equal to the ratio of their lengths.

Similarly, for a square beam, the cube of a side of the square varies as the length of the beam if the load remains the same.

EXAMPLE 1.—Find the diameter of a round cross-beam 14 feet long that will support the same load as an 8-inch round stick 10 feet long of the same material and loaded in the same manner.

SOLUTION.—Calling the required diameter x, then $x^3 : 8^3 = 14 : 10$. $\frac{x^3}{8^3} = \frac{14}{10} = \frac{7}{5}$; and,

$$x^3 = 8^3 \times \tfrac{14}{10} = 716.8,$$

$$x = \sqrt[3]{716.8} = 8.9+ \text{ or } 9 \text{ in., approximately. Ans.}$$

EXAMPLE 2.—Find the side of a square cross-beam 10 feet long that will support the same load as an 8-inch square stick 12 feet long of the same timber and similarly loaded and supported.

SOLUTION.— $x^3 : 8^3 = 10 : 8$

$$\frac{x^3}{8^3} = \frac{10}{8}$$

$$x^3 = \frac{5 \times 8 \times 8 \times 8}{4} = 640$$

$$x = 8.62 \text{ in. Ans.}$$

51. The transverse strength of any beam, that is, its resistance to bending, is proportional to the product of its width and the square of its depth. This explains why a rectangular beam laid on edge is stronger than the same beam laid flat, and also why it is better to increase the depth rather than the width of a beam in order to strengthen it.

For instance, if Fig. 15 (*a*) represents a 6″ × 12″ beam laid on edge and Fig. 15 (*b*) the same beam laid on its side, the relative strengths of two beams, thus placed, of the same material and similarly supported, will be $\frac{b\,d^2}{b\,d^2} = \frac{6 \times 12 \times 12}{12 \times 6 \times 6} = \frac{12}{6} = 2$; that is, a beam of these dimensions placed as at Fig. 15 (*a*) is twice as strong as a similar beam of the same length placed as at Fig. 15 (*b*).

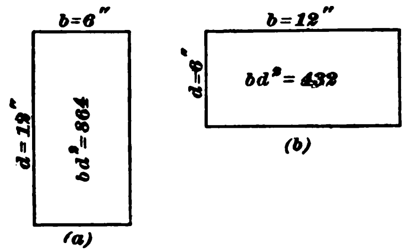


Fig. 15

If the load on a cross-beam or collar is more or less evenly distributed over the whole length of the beam, the load on the beam is proportional to the length of the beam. For example, a 16-foot collar under these conditions is assumed to support twice the load carried by an 8-foot collar.

From the formulas for square and round timbers given in Art. **47**, it is clear that the total load W supported by a beam varies as $\frac{d^3}{l}$. If, now, w represents the load per unit of length, the total load for a length l is $w\,l$; therefore, since $w\,l$ varies as $\frac{d^3}{l}$, w varies as $\frac{d^3}{l^2}$. Hence, for two beams of the same material and similarly supported in which w and w_1 represent the loads per unit of length, $w : w_1 = \frac{d^3}{l^2} : \frac{d_1^3}{l_1^2}$.

Under the conditions common to mining practice, for the same roof pressure or depth of cover, the load per unit of length on two beams would be the same, or $w = w_1$. Hence, $\frac{d^3}{l^2} = \frac{d_1^3}{l_1^2}$, or $\frac{d^3}{d_1^3} = \frac{l^2}{l_1^2}$. Or, in other words, the cube of the ratio between the diameters of two beams uniformly loaded is equal to the square of the ratio between the lengths of the two beams.

It should be carefully noted that this last relation is true only when the load per unit of length is the same on both beams. When the total load is considered, the rule given in Art. 48 applies.

EXAMPLE.—In a certain mine, 10-inch timber is used for the cross-beams where the entry is 14 feet wide; what should be the diameter of collars in the same mine where the width of the entry is 8 feet?

SOLUTION.—Let the required diameter of the 8-foot collars be x; then $\left(\frac{x}{10}\right)^3 = \left(\frac{8}{14}\right)^2 = \left(\frac{4}{7}\right)^2 = \frac{16}{49}$; and,

$$x = 10\sqrt[3]{\tfrac{16}{49}} = 10\sqrt[3]{.32653} = 6.88, \text{ or 7 in., approximately. Ans.}$$

METHODS OF TIMBERING

SINGLE-STICK TIMBERING

TIMBERING FLAT SEAMS

52. The system of timbering used in flat coal seams depends on the nature of the roof and floor and on the height and width of the opening. The term **single-stick timbering,** while strictly applicable only to timbering where one upright, inclined, or horizontal piece of timber is used, is commonly applied also to combinations of two or more pieces of timber that are put together more or less loosely, but without notching and jointing.

53. Props.—The simplest form of timbering is a prop stood under any portion of the roof that is liable to fall. Sticks of timber that are used for this purpose are chosen with a view to the weight they are to sustain; consequently, they vary from large-sized to small-sized round logs, and in some cases a log is split into several pieces to make what are called *split props.*

A prop should be placed perpendicularly in a flat seam so that any weight that comes on it may act vertically downwards through the center of gravity, as shown in Fig. 16 (*a*), and not to one side, as shown by the dotted line in Fig. 16 (*c*). A straight prop is always preferable to a crooked one, for if the stick is crooked, as in Fig. 16 (*b*), the fibers do not equally sustain the pressure and some fibers sustain more than their share, causing them to bend and the stick to break, or to fly out of place. For similar reasons, props should be squared at their ends and rest firmly on the floor, as in Fig. 16 (*a*), and not be placed as in Fig. 16 (*c*) or (*d*), for in the latter case only that portion of the prop to the

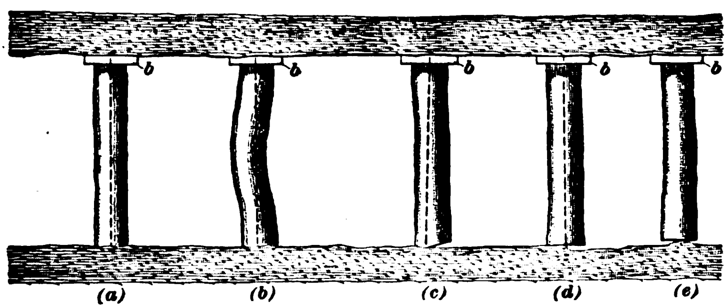


Fig. 16

left of the dotted line sustains the pressure. If only a portion of the base is thus supported, the advantage of a large prop is lost; and, moreover the post will split, bend, or fly out when the weight comes on it. If the prop rests on a point, as shown in Fig. 16 (*e*), this point will act as a wedge to split the prop.

To avoid setting props as in Fig. 16 (*c*), (*d*), and (*e*), and to afford a flat bearing for the roof and floor, props are sawed square at the ends, made 2 or 3 inches shorter than the height of the opening and wedged into place by a cap piece *b* made of strong plank. Miners frequently use an ax to cut down a prop when it is too long, but this is bad practice where permanent work is being done, because the ax leaves an uneven end and the full section of the timber does not sustain weight; this will result eventually in the cap or prop splitting.

The object in placing props is to prevent any sag in the roof, or else to control the amount of this sag, and is not to sustain the whole weight of rock above the props; therefore, the connection between the floor and roof should be rigid and unyielding. If the props were cut to nearly the exact length, this could only be approximately accomplished because the walls vary some; but where wedge-shaped caps are used, rigidity is obtained. In many cases, props that are not thus placed are worse than none, for they invite injury by suggesting security.

FIG. 17

54. Occasionally, when a prop is short or the cap thin, miners place the foot of the prop on a little built-up mound of dirt, or on a foot-piece placed on a mound of dirt, Fig. 17, and then wedge the cap above. The practice is legitimate

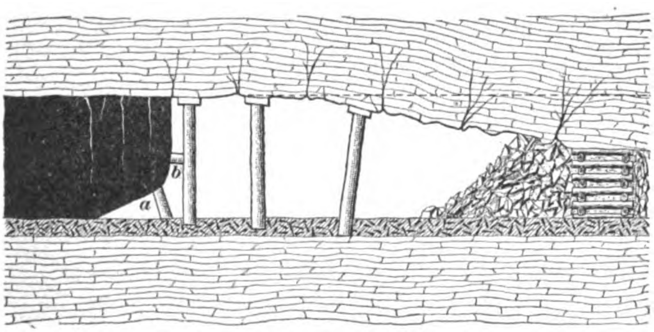


FIG. 18

in long-wall mining where the roof necessarily sags, as shown in Fig. 18, and where props are withdrawn to cause the roof to fall; but in room-and-pillar mining it is poor practice and may cause disaster, for the dirt will give, particularly where it is coal and slate, and this little may be sufficient to let the roof sag and break down. Some miners place a plank on the floor for such short props and then drive in the cap pieces. While this is better practice than the dirt mound, an even floor and thicker cap or even two caps are preferable. Fig. 18 also shows how the props may be driven into a soft bottom, thus gradually relieving the weight on the prop without breaking it. *a* and *b*, Fig. 18, are short sprags used to support the face.

55. Props Set Butt Up.—In some localities, the butt end of the prop is placed toward the roof in order to afford more surface for the cap to rest on. This position is unstable and the stick is also harder to handle, but the butt end up gives greater bearing surface at the point where the prop is wedged and driven.

FIG. 19

Whether posts should be set with their butt ends up or down is largely a matter of opinion, as practice differs in different localities. Some timbermen set the thick end down, while others set the larger end against the weaker stratum, be it top or bottom. The splitting or furring of the post is more apt to take place at the small end, and many prefer that this should occur at the bottom rather than at the top where the cap or other timbers are resting on the post.

Soft-wood wedges, or caps, do not snap or break off so readily as hard wood, and soft wood, by yielding, distributes the pressure more uniformly over the end of the post, and binds the fibers of the post together as a hoop, thereby lessening its tendency to split.

56. Tapered Props.—Props are sometimes tapered, as shown in Fig. 19, in order to reduce the strength of the prop at the end so that it will crush or splinter at the tapered end instead of breaking, as the pressure gradually comes on the prop. This pressure is gradual and irresistible in longwall work until the roof settles on the packs. The tapered end allows the settlement to take place without injury to the post, which still retains its strength and supports the loose pieces of rock, which would otherwise fall.

57. Draw-Slate Timbering.—The slate above and next to coal beds is termed **draw slate** when it separates readily from the rock above. If the draw slate is not more than 3 inches thick, the best plan to follow is to take it down, since it is affected by the air and becomes too weak to be held up with props; in fact, it will fall away about a prop. When the draw slate is from 3 to 6 inches thick, it is customary to place props along the gob side of the track and at a sufficient distance from the rib to allow cars to pass, as shown in Fig. 20. These props are to hold up the draw slate over the track and permit the remainder to fall into the gob. In such cases, a large cap piece *a*, Fig. 21, extending over the track from each prop and with one end set in a hitch in the rib, is often used; lagging *b* is then laid lengthwise over these caps. The cross-bar is not usually connected to the prop by cut joints, but is merely laid on top of the prop and is therefore only a long cap piece with both ends supported.

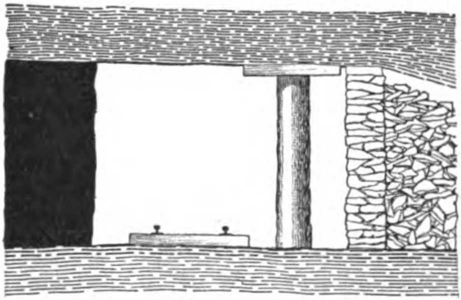


FIG. 20

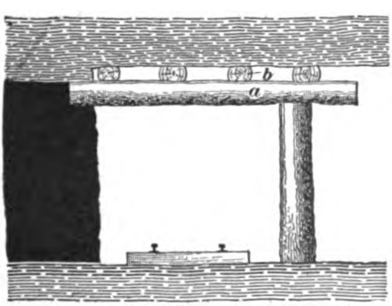


FIG. 21

The sticks used for this purpose are about 6 inches in diameter; sometimes split props are used, as this timbering is of a temporary nature and is needed only until the room is worked out.

When the draw slate is more than 6 inches thick, a row of strong props is placed through the center of the room; provided that the room is not more than 16 feet wide and the slate is comparatively strong. Such an arrangement is shown in Fig. 22, in plan, where *a* is the rib, *b* the track, *c* the props, and *d* the gob. Should any cracks *ef*, *gh* be found in the draw slate, this cracked area must be taken down from over the track, otherwise it is liable to fall and leave the prop sustaining only a small portion of the slate *i*.

58. Draw slate usually falls a little at a time, but it may fall across the room; if, therefore, the room is over 16 feet

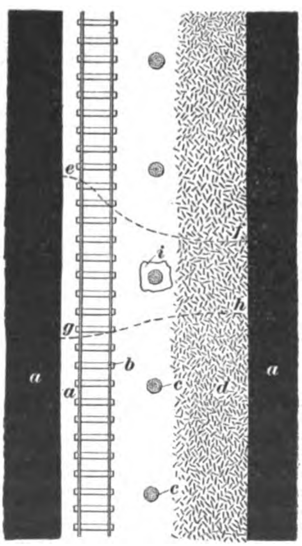


FIG. 22

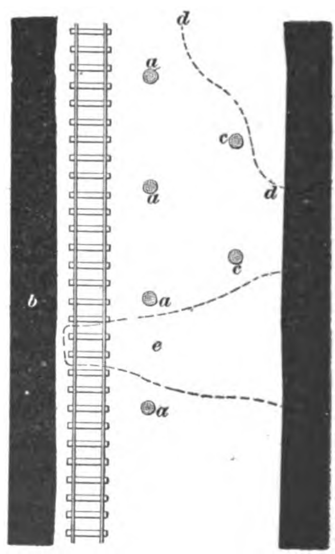


FIG. 23

wide and the draw slate is 6 inches or more thick, two rows of props should be placed, one *a* about 8 feet from the rib *b*, Fig. 23, and the other *c* about 15 feet from the rib *b*, the props *c* being staggered with respect to props *a*. The draw slate would thus be prevented from falling on the track and the falls would be confined to the gob side, as shown by the dotted line *dd*. On the other hand, if there were no props *c*, the fall might extend in between the props *ab*, as at *e*. The distance apart of the props depends on the thickness and the exact condition of the draw slate, but it is usually better to place the props at regular intervals.

59. Testing the Roof.—Draw slate is treacherous and the miner should always sound the slate with his pick before working under it. A small thin piece can make painful wounds and often causes loss of life. If, on tapping it lightly, the roof gives a hollow or cracked sound, the slate should be taken down. If such slate be tapped hard, it may be cracked by the blow and its fall hastened. Tapping is not always a sure sign that slate will not fall, but it is the chief guide the miner has to depend on and will usually prove the roof, excepting where there are "**kettles,**" or "**bells,**" *a*, Fig. 24, which cannot be detected by sound. Kettles are fossils found in the roof and are conical in shape or like a truncated cone and are evidently the petrified stumps of trees. When the coal is mined from beneath them, tapping does not disclose their presence; but as the air gets at these fossils, they loosen and often fall without warning.

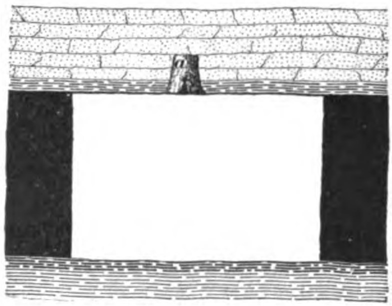


Fig. 24

60. Slips in the Roof.—Certain roof rocks, such as sandstone and slate, are often jointed or cracked, as is shown in Fig. 25. Such a roof is very dangerous to work under, especially where the slips are inclined backwards over the miner, as shown, for the miner is not warned of the presence of such a slip until he has undercut the coal, which will fall and allow the slate to fall also.

When the roof is known to be of this character, the props should be close together and should be kept as close to the face as possible, Fig. 25. A long cap piece is used to support the rock on both sides of the crack. The position of the post with reference to the crack will depend on the inclination of the crack. For instance, if the fracture, as *a*, Fig. 25, is vertical, the post *b* should be directly under it; but if inclined, as shown at *c*, the post *d* may be under the point of the piece of rock. The post should be vertical and the cap driven into place by a sledge or maul so that a rigid connection is made from the roof to the floor through the post.

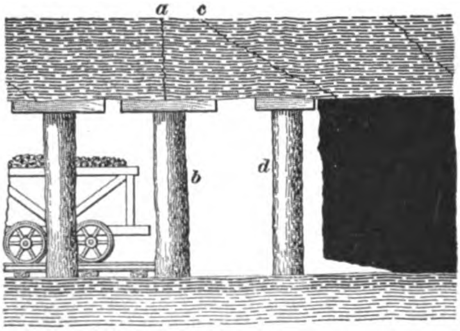


FIG. 25

61. If the props are not kept well up to the face under a cracked roof, but are allowed to lag behind, as is so often done, a serious accident may result, as is illustrated in Fig. 26. A prop with a large cap should be placed wherever a crack shows, particularly if the roof slate is thick. The cap is usually larger and thicker than in ordinary prop timbering under a uniform roof and is usually placed at right angles to the crack. The prop must be strong and able to sustain the weight of the broken piece of rock above, for such rocks have no tenacity and almost their entire weight will rest on the props.

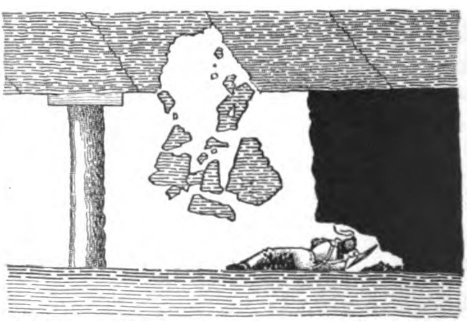


FIG. 26

62. Sometimes the caps are made long enough to rest on two props, as shown in Fig. 27. The caps *a* are placed on the props *b*, but are not notched as in two- or three-stick timbering, being made secure by the wedges *c*. In all cases, they should have a regular arrangement through the room. Props for timbering under a cracked roof should be about 8 inches in diameter and the caps about 6 inches thick. The props should be about 8 feet apart, but the cross-bars can project 18 inches over their ends. After the room is com-

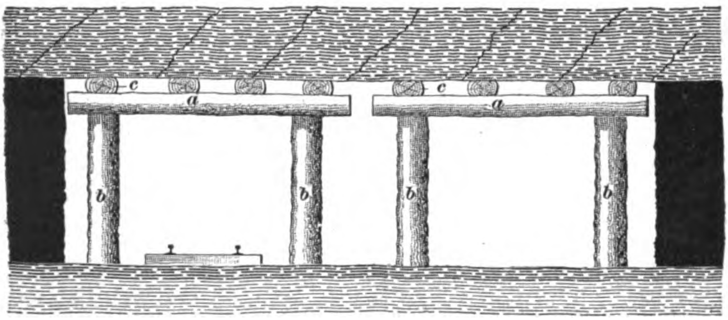


FIG. 27

pleted and the track removed, such timbering may be drawn and saved for future use, the roof then being allowed to fall. It may be necessary, in some extreme cases where the cross-joints occur, to have two sets of cross-bars, one across the room and the other parallel to the ribs.

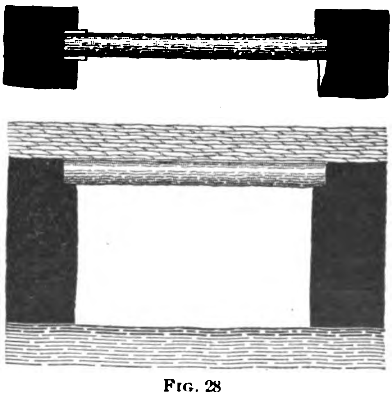


FIG. 28

In narrow places, a cross-bar set in hitches in the rib on each side, as shown in Fig. 28, may be used to support the top; in such cases, the hitch made at one end must have one side inclined so that the stick of timber may be driven into place. It is frequently wedged at the ends in order to keep it solidly in its place.

63. Timbering is varied to meet the conditions of the roof at each mine; therefore, at mines with good roofs, but little is needed, but it is always safe practice to timber under sags in the roof, as these suggest the bed of a stream of water in the past and an opportunity for its accumulation in the present; in fact, in flat beds, water is nearly always encountered in depressions of this kind. If the roof and bottom are both hard, the props are driven in as solidly as possible, the number of props used and their arrangement depending on the width of the opening and the nature of the roof, whether it is firm or shaly. In long-wall work, where the roof is allowed to settle gradually, the props may be set on mounds of dirt, as shown in Fig. 17. Where the roof or the bottom is soft, extra large cap pieces or foot pieces are used, so as to give as great a bearing surface as possible between the top or bottom and the props.

64. Supporting the Coal Web.—As the coal is being undercut, it is usually necessary to support the web of coal over the miner's head to prevent its falling on him. The simplest method of doing this is by means of a *sprag* *a*, Fig. 29, which may be placed either at the opening of the undercut, or may be placed within the undercut.

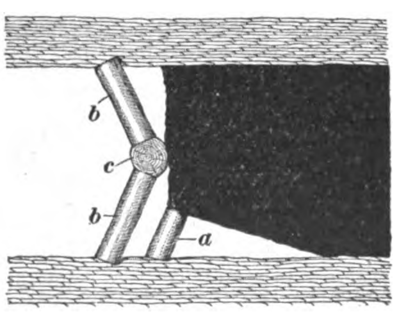


FIG. 29

The combination of timbers *b c* used for supporting the face is termed a **cockermeg.** It consists of two braces *b* between which a horizontal stick of timber *c* is placed along the face. If the angle that the braces *b* make with the vertical is less than 20°, they will not slip and they may be driven tightly against the roof and floor so as to bear against the stick *c*. If the braces *b* are placed at a greater angle than 20°, the ends should be put in hitches as shown.

SINGLE-STICK TIMBERING IN INCLINED SEAMS

65. When the bed is inclined, the props are usually inclined up the slope and are not placed at right angles to the roof and floor, as in a flat bed. The object of so inclining props is shown in Fig. 30, where *a* is a prop at right angles to the roof and floor and *b* is a prop given an *undersetting*, that is, a slight inclination up the slope. Any movement of the roof will cause the prop *a* to move in the arc shown by the dotted lines and fall down. On the other hand, any movement of the roof will tend to cause the prop *b* to move in the arc shown and crowd against the roof, thus preventing it from falling. Undersetting is admissible on a pitch, because the prop does not transmit all the pressure from the roof to the floor, as in flat beds; for in the flat bed the pressure is directly on the prop, while in the pitching bed the pressure on the prop decreases as the inclination of the bed increases until the bed is vertical, when the pressure becomes zero.

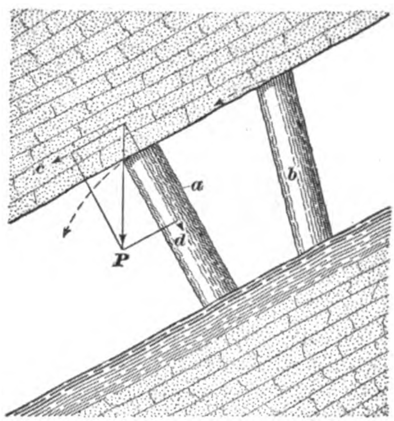


FIG. 30

A prop in an inclined position, particularly where the inclination is steep, is sometimes called a *stull* in coal mines, and is nearly always so called in ore mines.

In Fig. 30, let *P* represent the pressure; this may be resolved into two components, one acting in the direction *c* parallel to the dip and the other in the direction *d* perpendicular to the dip. The component *c* is resisted by the rock in place below it and the component *d* by the prop. It is evident that the more inclined a bed is, the more closely the direction of the pressure *P* will approach the component *c*; and that, when the bed is perpendicular, *P* and *c* will be in the same line and there will be no pressure in the direction *d*. When a bed is vertical or very steeply inclined, stulls, or cross-beams, will be needed to prevent pieces of loose rock from falling from the sides.

66. To prevent the coal from falling on the roadway, it is also often necessary to place a series of props as shown in Fig. 31. The prop *a* is underset, its foot being placed in a hitch in the floor. Part of the draw slate *b* is taken down to prevent its falling and the remainder is held up by the prop *a* and cap *c*. To prevent the coal from falling into the gangway, the props are placed short distances apart and covered over with stout lagging *d*. It is necessary to wedge the foot of the prop and drive the cap *c* in tightly; then, any movement of the roof will tighten the joint between the prop and the cap.

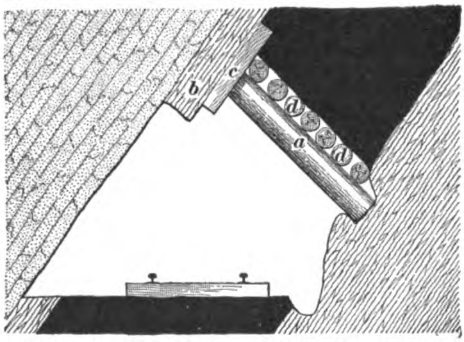


FIG. 31

67. If the seam is very steeply inclined, so there is danger of the cap between the roof and the prop slipping out, a hitch is cut in the roof rock so that the prop may have rock rests at each end. The pressure that the prop then has to sustain is from the coal, and the prop is in the position of a beam uniformly loaded along its length. This system, shown in Fig. 32, is the better method in highly inclined beds, but the hitches cut in the roof must be at least 12 inches deep and the prop thoroughly wedged at both ends. The object

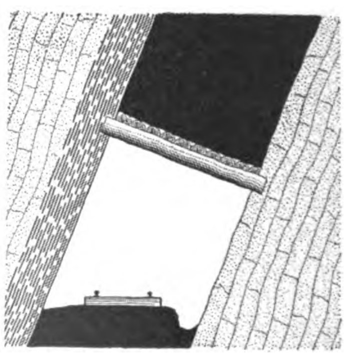


FIG. 32

of wedging timbers when placed in such positions is to give them stiffness, for if they bend they will eventually break; by wedging the ends, the bending is, in a great measure, prevented.

68. Fig. 33 shows the method of timbering a wide coal bed at one mine in Pennsylvania. The logs *a* were about 20 feet long and 18 inches in diameter at the top. They were placed 8 feet apart and lagged with 8-inch round sticks. Handling these sticks and placing them were laborious operations and the method is not recommended.

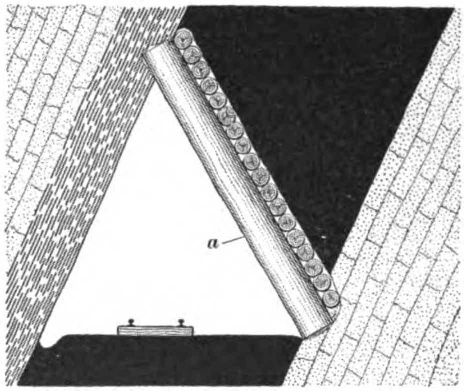


Fig. 33

69. The use of single props for timbering deposits exceeding 12 to 15 feet in thickness is limited, as large, heavy timbers must be handled in such cases, making the system an expensive one; furthermore, the resistance of a prop to bending is not great when the length is more than twelve to fifteen times its diameter.

TWO-STICK TIMBERING

FLAT SEAMS

70. Post and Bar.—Two timbers may be joined in a variety of ways and used for supporting the walls of mine excavations. Fig. 34 shows a hitch *a* cut in the coal to receive the cap *b*. This hitch should be 12 or 15 inches deep and only high enough to receive the cap. The post *c* is then put close to the rib *d* and made firm by the wedge *e*, after which the wedge *f* is fitted in place. Care must be taken when inserting the wedge *f* to see that the coal on which it rests is even, for otherwise the wedging will break down the coal; it is safer, when the coal is soft, to place a plank in the hitch, which is made longer than the width of the bar, and then to drive wedges between the bar and the plank; this arrangement offers more bearing surface on the coal. The same kind of timbering may be placed over the roadways in rooms, as is shown in Fig. 21.

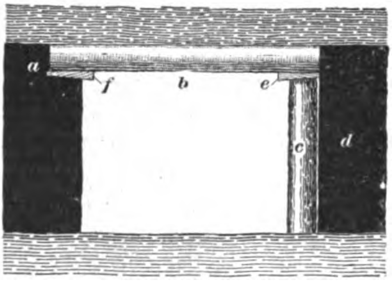


FIG. 34

71. Post, Bar, and Lagging.—Where the draw slate is to be supported, it may be necessary to use lagging in connection with the post and bar. Fig. 35 shows the method often advised for timbering under such conditions, and while it may do well enough in hard rock it is not suitable for coal mining. In the first place, the bar *a* rests on a small piece of coal *b*, which a little pressure will break down; hence, with such timbering, the rib *c* should be vertical. In order to drive the lagging *d* over the bar, the draw slate *e* has been gouged out, which is bad practice, since it weakens the roof and permits water to come on to the roadway. The leg *f* is slanted; consequently, it is not so strong or capable of sustaining pressure as it would be if stood upright. The coal from the rib *g* is apt to fall into the gangway, in time, to a greater extent than would be the case were the rib made vertical. The proper method in such situations is similar to that shown in Fig. 34, where the ribs are straight, the post is set vertically, and the roof is not broken. Lagging, if required, may be extended from one

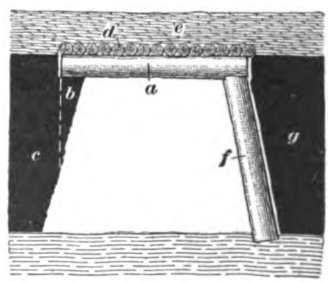


FIG. 35

bar to the next, these being placed at distances apart that depend on the thickness of the draw slate. The lagging at the corners of the bar act as wedges and should be driven in with particular care, as they will exert a great influence in stiffening the bar.

72. Instead of having the post the full height of the opening, a method sometimes used is to have short posts set on a

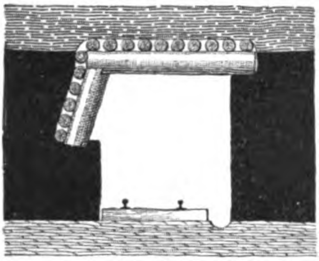


FIG. 36

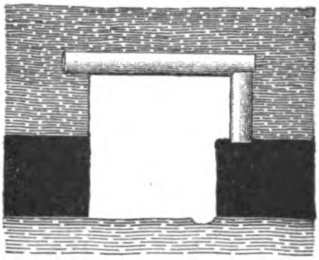


FIG. 37

ledge in the coal, Fig. 36, or on top of the coal when the top rock is taken down, as shown in Fig. 37.

INCLINED SEAMS

73. Fig. 38 shows a method of timbering that may be used in thin coal beds that are not highly inclined, and where the floor must be blasted in order to obtain headroom in the entry. The coal would fall on the entry if the collar *a* were not lagged over. The pressure *p* on the collar *a* is resolved into two components, one acting at right angles to the collar in the direction of the arrow *b* and the other parallel and lengthwise of the collar in the direction of the line *c*. To stiffen the collar, it must be

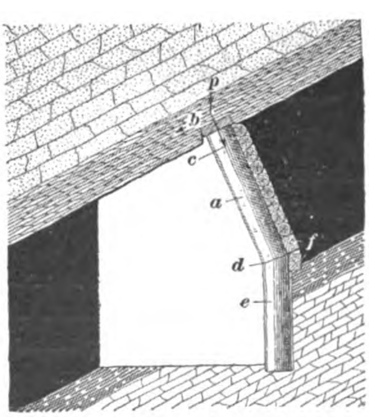


FIG. 38

thoroughly wedged at *d* and at its joint with the leg *e*, by wedges *f*. This is a good form of timbering, provided that the wedges *f* are tight so that the greater part of the pressure on the collar will be transferred along the leg *e*. The beveled joint will become tighter if the side pressure from the coal increases.

74. Fig. 39 shows a similar form of timbering where the roof is supposed to be strong and where there is very little roof pressure. The joint between the post *p* and the bar or collar *b* is a weak one, and is not nearly so strong as the one

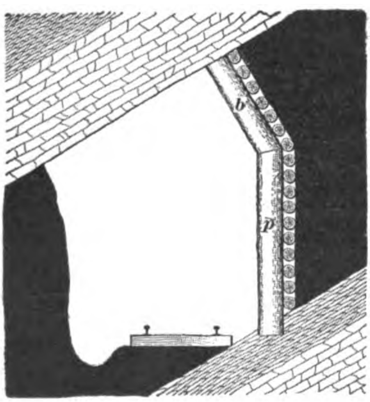


FIG. 39

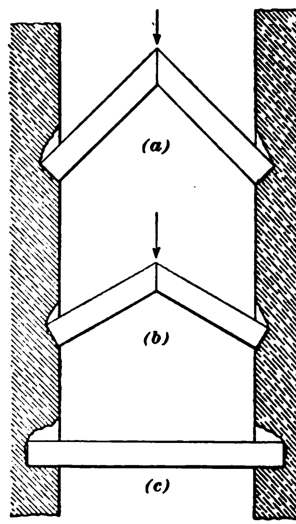


FIG. 40

shown in Fig. 38, where wedges are used. This arrangement is intended more to keep back the coal than to support the roof.

75. Inclined Timbers.—A post or prop will support a greater load than a beam, since a post is under compression while a beam is under shear and the compressive strength of wood is greater than its shearing strength. Consequently, timbers arranged as shown in Fig. 40 (*a*) and (*b*) are stronger than the beam shown in Fig. 40 (*c*). The greater the inclination of the timbers, the greater is their strength, because the greater the inclination, the more nearly do they approach the action of posts in their resistance to pressure.

76. Fig. 41 shows a case where one of the timbers *a* is more steeply inclined than the other. The pressure *P* applied at the point *c* and represented by the line *cd* may be resolved into two components, *ce*, acting along the length of the timber *a*, and *cf* acting along the length of the timber *b*. The forces *ce* and *cf* may, in turn, be resolved into horizontal and vertical components, as shown. Since *cg*, the vertical component of *ce*, is greater than *ch*, the vertical component of *cf*, the timber *a* receives a larger amount of the pressure applied at *c* than does the timber *b*.

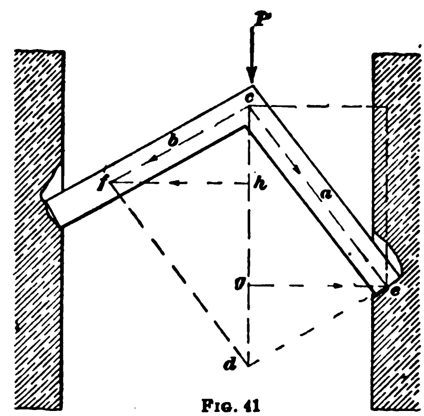


FIG. 41

In a mine, however, the pressure is usually distributed over the timbers, and the less inclined of the timbers may be subjected to a greater shearing stress than the more steeply inclined one. These points should be borne in mind, as it is often necessary to use timbers in this way in the mine.

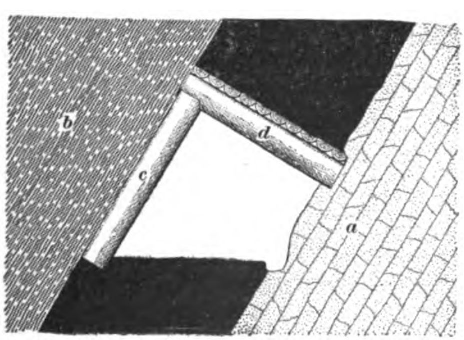


FIG. 42

77. Fig. 42 shows a system of two-stick timbering where the coal seam is narrow and the bed inclined. In order to obtain headroom, it is necessary to cut away a portion of the foot-wall *a*. The top rock, or hanging wall, *b* is good, but to prevent the leg *c* being pushed into the roadbed the foot of the leg is placed in a hitch in the coal and the joint with the collar *d* is notched as shown. The collar *d* is lagged to keep the coal from falling on the roadway. If the top rock *b* is poor, the leg *c* can also be lagged. Seasoned lagging should be used in such places, and split lagging with the flat side laid in is preferable, since the rounded side is stronger in compression than tension.

THREE-STICK TIMBERING

78. Timber Sets.—When mine passageways have three weak sides, **timber sets** are used. Each set is composed of two legs *a*, Fig. 43, which support a cap piece *b*. The distance apart of the sets along the entry depends on the nature of the material to be supported. Where the walls are very weak, the sets may be placed skin to skin, as shown in Fig. 44; ordinarily, however, they are placed from 3 to 4 feet apart, and if the ground is loose, lagging *c* is placed back of them, as shown in Fig. 43.

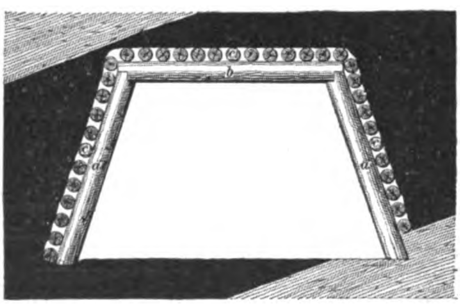


FIG. 43

Three-stick timbering is sometimes called *double timbering*, a designation that is used for it in South Wales. The term double timbering, however, usually signifies a duplication of timbers, either one set above another, one collar above another, or one prop in front of another, to give double support.

79. Limiting Angle of Resistance.—In Fig. 43, the legs of the timber set are inclined so that the pressure coming on the collar is transmitted equally to both legs. If the legs were placed at different angles, the pressure would bear unequally on them, the greater pressure coming on the leg making the smaller angle with the vertical. The tendency for the foot of a post to slip increases with the inclination; and if the angle between the post and the vertical is more than 20°, the post is apt to slip, but the legs are not apt to spread on a level rock surface when this angle is less than 20°. It is, of course, possible to block the foot of the leg against the side of the gangway, but even then the horizontal pressure against the foot of the post increases rapidly and it is advisable to keep the inclination of the legs less than 20° from the vertical.

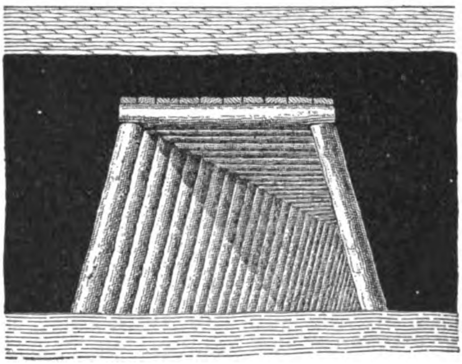


FIG. 44

80. Placing Timber Sets.—It is important in the framing of a set of timbers that the joints between the two pieces of timber be accurately cut so that the bearing surfaces are in close contact. The lower end of each leg must also be cut so as to be in contact, over its whole surface, with the floor in order to get the full benefit of the cross-section of the timber. An experienced timberman will usually cut these ends by eye, but a templet is sometimes used to get the proper angles; sometimes, the timbers can be framed entirely on the surface so that they are ready to put in place when they are delivered in the mine. In wedging the cap piece, care should be taken that the wedges are driven as uniformly as possible over the full length of the cap piece; for if some wedges are driven more tightly than others, the weight will be concentrated at these points, at which place the cap is apt to break. In placing wedges, care should be taken to properly secure the roof without throwing an unnecessary strain on any part of the timber set.

81. Timber Joints.—Fig. 45 shows a joint sometimes used to resist pressure from above rather than from the side. The joint is objectionable from the fact that continued pressure on the collar *a* will cause it to sag, and thus raising the scarf *b* of the joint from the post *c* will throw all the weight on the part *d*. This has a tendency to split the post *c* and the cap *a*, as shown by the dotted lines; if this occurs, the entire weight is thrown on the collar above the dotted line *e*, and on the part of the post to the left of *d*, the part *d* and that below *e* being useless in sustaining weight. The same bending trouble will take place, but to a lesser extent, if the timbers are joined as in Fig. 46, unless the wedge *f* stiffens the collar sufficiently to prevent its bending; it is doubtful, however, if sufficient stiffening would occur when continued heavy pressure comes on the collar. In case the collar *a* bends so as to open the joint *b*, the upper part above *e* is useless for sustaining pressure. The side wedge *g* is intended to keep the joint tight.

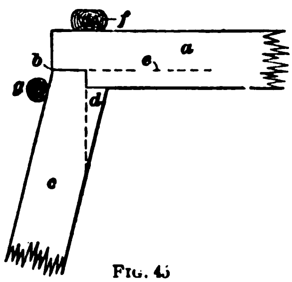


FIG. 45

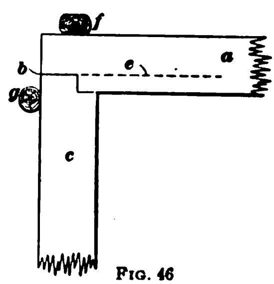


FIG. 46

82. The joint in Fig. 46 is better able to withstand pressure from above than that in Fig. 45, for the pressure is along the fibers of the post *c* and not across them.

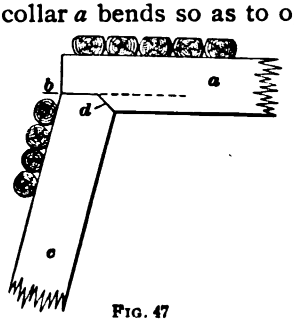


FIG. 47

The joints in Figs. 47 and 48 have proved very satisfactory in practice, as the timbers are not so apt to split as when the joints shown in Figs. 45 and 46 are used.

If the cap begins to sag, there is much less chance for the joint shown in Figs. 47 and 48 to open than there is with

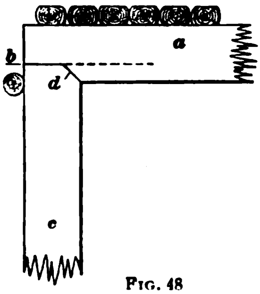


FIG. 48

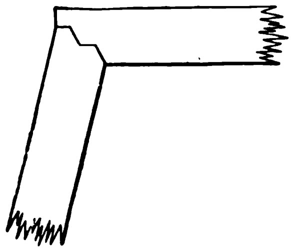


FIG 49

the joint shown in Figs. 45 and 46, as there are no sharp angles in the joint between the timbers *a* and *c*. The pressure also comes on the faces *b*, *d* of the joint much more uniformly, and the absence of the heel or sharp corner in the joint also greatly reduces the tendency of the cap to split along the dotted line.

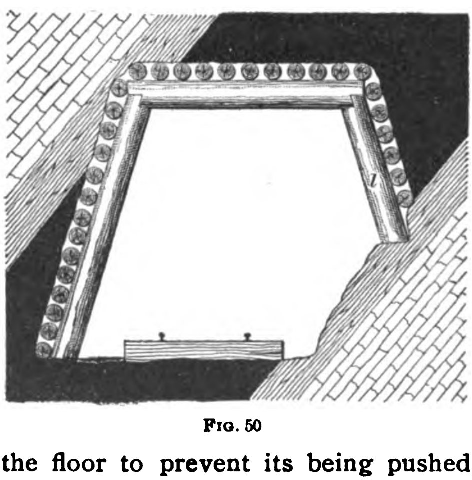


FIG. 50

83. In case the side pressure is greater than the top pressure, the leg is given an inclination less than 20° from the vertical and a double-notched joint is made, as in Fig. 49. The foot of the leg is placed in a hitch in the floor to prevent its being pushed inwards.

84. Fig. 50 shows the method of timbering when the angle of dip is great, the bottom hard, and the seam is not thick enough to give full height for the entry. This method avoids the cost of taking out enough rock to get in a set of timber having equal legs. The shorter leg *l* is given a firm hold on the rock bottom.

85. Fig. 51 shows a form of timbering used in pitching

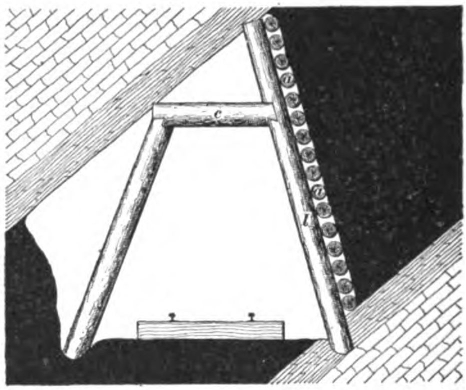


FIG. 51

seams where the coal is soft, and falls to a height greater than that required for the gangway. The leg *l* on the high

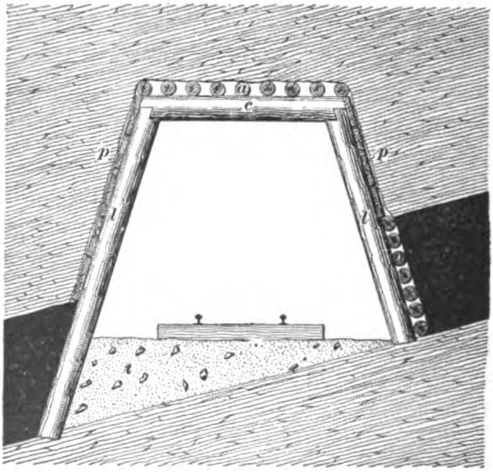


FIG. 52

side is made long enough to reach up to the roof to support the lagging *a*, *a*, which keeps the soft coal from continually sliding down into the gangway. The collar *c* strengthens the leg *l*. The coal is allowed to fall off on the low side where no lagging is necessary.

86. Fig. 52 shows the method of timbering the levels in thin pitching seams, when the top is supposed to be weak. The legs *l*, *l* and the collar *c* are made of round timber about 12 inches in diameter, and are so jointed together that the collar *c* will stand great pressure. The lagging *a*, *a* consists of round poles taken direct from the woods, and usually from 3 to 6 inches in diameter. The poles are used to keep the loose coal and roof from falling between the sets of timbers, which are from 3 to 5 feet apart. Where the lateral pressure is slight, planks *p*, *p* are used. The road is made level by filling in the low side with refuse *t*, as shown in the figure.

FOUR-STICK TIMBERING

87. Pressure may come from both sides and from the roof and floor of an excavation, in which case it will be necessary to use four sticks for a timber set and either lag behind them or place them skin to skin. A method of framing such sets is shown in Fig. 53. In some instances, the legs are tenoned for a mortise in the sill, but this is unnecessary if the angle the leg makes with the vertical does not exceed 15°, which, according to Morin's experiments, is the limiting angle of contact of oak on oak when the fibers of the moving surface are perpendicular to the surface of contact and those of the surface at rest are parallel to the direction of the motion. In Fig. 53, the moving surface is the lower end of the inclined leg and the surface at rest is the portion of the sill on which this end of the leg rests. The friction of two surfaces that have been, for a considerable time, in contact and at rest, is different not only in

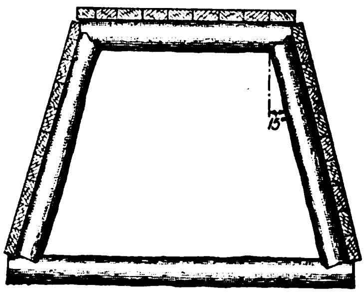


FIG. 53

amount, but also in nature from the friction of surfaces in continuous motion. A jar or shock producing an almost imperceptible movement of the surfaces of contact causes the friction of contact at rest to pass to that which accompanies motion.

88. If the leg *a*, Fig. 54, is let into the sill *b* as shown, the pressure *p* along the leg may be resolved into the two components *c d* and *c e*. The more nearly vertical the leg *a* is, the greater will be the component *c d*, which is resisted by the cross-grain of the wood, and the stronger will be the joint. The tendency of the leg *a* to slip is also less the more nearly vertical *a* is. If the leg *a* is bent inwards, the heel *f* acts as a fulcrum of a lever and the corner *e* tends to split off the block above the line *eg*.

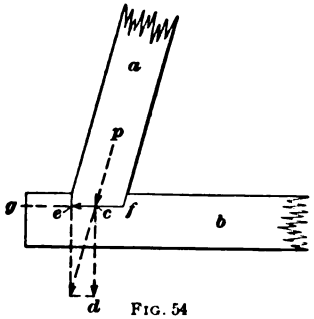


FIG. 54

89. If the leg *a*, Fig. 55, is jointed to the sill *b* as shown, there is less danger of its slipping or of its splitting the timber than when the joint shown in Fig. 54 is used. The pressure *p* acting along the leg *a*, Fig. 55, can be resolved into the two components, one *c d* acting vertically and across the grain of the wood, and the other *c e* acting parallel to the grain of the wood. In this case, if the leg *a* bends toward the right, the tendency is for the heel *f* to split the sill along the line *fg*, but the length of wood fiber *fg* in this case is longer than the length of wood fiber *eg* in the joint shown in Fig. 54, and there is, therefore, not the same danger of the block above *fg* splitting off. Again, in case of a sudden shock, the wood tends to slide along the face

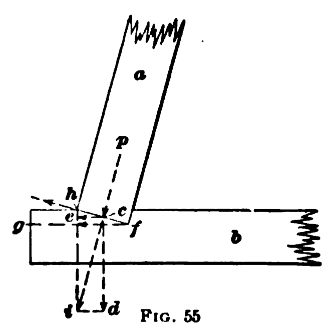


FIG. 55

f h, that is, perpendicularly to the direction in which the pressure is transmitted along the leg. The timber *a* could not, therefore, slide on the timber *b* as readily with the joint in Fig. 55 as it could with the joint in Fig. 54, where the angle of inclination between the faces of the timber is greater. In other words, with the joint in Fig. 55, there will be much more friction between the faces of the timber to oppose movement than with the joint shown in Fig. 54; and to start a movement of the leg, the jar must be much more severe.

TIMBERING TURNOUTS

90. Turnouts, in coal mines, are usually from 12 to 16 feet wide. Sometimes a single row of center props will be sufficient to support the roof. If the span is not too great, cross-timbers set in hitches, as illustrated in Fig. 28, may be used. It is generally better, however, to support the cross-timbers by center props, as shown in Fig. 56.

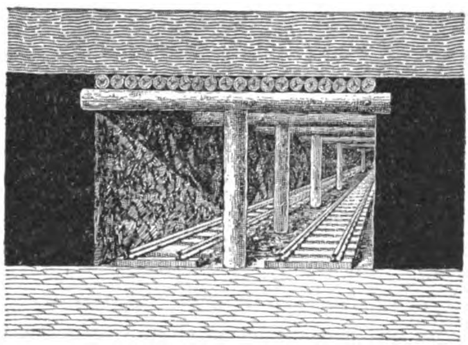


FIG. 56

91. Fig. 57 shows a very common method of timbering a turnout and is an adaptation of an ordinary three-piece set used for narrow passageways with the addition of the center post to strengthen the cross-timbers. The use of such a center post permits a smaller and lighter cap piece to be used. This same system of timbering is frequently used on slopes.

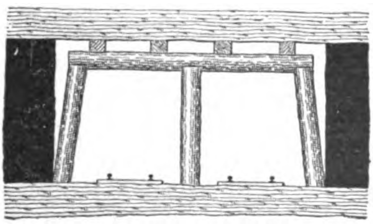


FIG. 57

92. Another method of timbering turnouts is shown in Fig. 58, where the center post is discarded and in its place five other timbers are used. This system is used in Europe and might find favor in some positions in American coal mines. The ordinary three-piece set composed of the timbers *a* and *b* is first put in place and this is reenforced by the timbers *c*, *d*, and *e*. The objections to this system of timbering are its cost and its interference with the air-current, when placed on haulageways. It is a serviceable method of timbering stables and engine rooms below the surface.

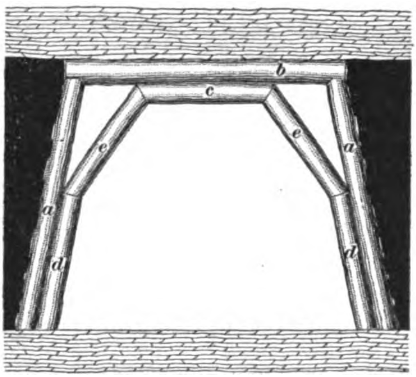


FIG. 58

TIMBERING SWELLING GROUND

93. Swelling ground is ground, such as fireclay, that, when exposed to air and moisture, softens and swells. It gives but little trouble during excavation, but soon begins to swell and to fill up the roadways. It is particularly troublesome where a thin seam is mined and it is necessary to lift the bottom or take down the top to give sufficient headroom. At times, nothing seems able to resist this swelling action except the removal of the material, and this may only be a temporary relief.

In timbering an opening through such ground, the best method seems to be to use fairly strong timbers and to excavate some of the material behind them whenever the swelling begins to exert too great a pressure on the sets. The lagging is usually light and open in construction, and by its bending or breaking, the miner is warned that the sets are in danger of being crushed and must be relieved. In some cases where the pressure is not so great, strong timber sets placed close together will be able to resist the pressure. Skin-to-skin timbering, illustrated in Fig. 44, or any of the forms shown in Figs. 43, 50, and 52, with the sets placed close together and closely lagged, may be used. Double sets of timber, one outside the other, are also sometimes used, or sets placed inside, as shown in Fig. 59. The longitudinal timbers *a*, *b* are usually about 10 feet long, though this length is varied to suit the ground. These are temporarily held in position while the struts *c* and *d* and the cap piece *e* are driven into their permanent positions. The lower ends of the struts *c* are set away from the timbers for the purpose of further strengthening the resistance to lateral pressure.

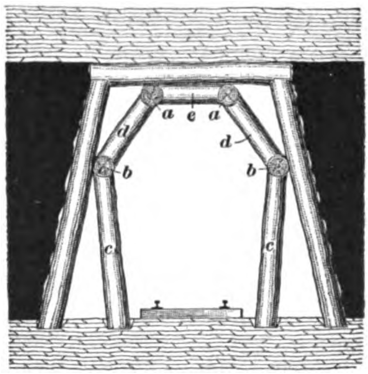


Fig. 59

Lagging may be placed behind either of the reenforced sets of timber illustrated in Figs. 58 and 59.

DRAWING TIMBER

94. Reasons for Drawing Timber.—After the necessity for supporting the roof has passed, the timber is sometimes removed, or **drawn.** This is done to allow the roof to fall and thus relieve the pressure on the pillars, or else to bring the overlying weight on the coal face in the long-wall method of working. The props are also sometimes removed, in order to save the timbers, as a prop can frequently be used several times; and even when it is broken it can be utilized for cap pieces or in building chocks or nogs. After the timber has been withdrawn, the roof settles regularly and the pressure on the coal face or on the ribs of the pillars is relieved. If this is not done, the pressure on the face becomes excessive and the quantity of lump coal obtained is decreased, and the amount of slack is correspondingly increased. In order to decrease this pressure on the face, the timber should be removed as quickly as possible, consistent with safety. Although timber drawing is dangerous work, the danger of a creep or squeeze may be greatly increased if the timber is not drawn.

95. Great judgment and experience are required to adopt the best order of drawing props, especially where there is a considerable area of waste. It may be best to leave a few props behind to assist in recovering the others with a little more safety. Where the top is too dangerous, the props must not be drawn if there is danger to the workmen in so doing. Removing one prop sometimes starts the roof, which falls, bringing a number of posts with it. The props in the rear row should be drawn first. Not more than one prop should be drawn at a time, and there should be perfect silence while this is being done. There should never be less than two or three men present who take part in this work.

Timber drawing in connection with the cutting down of top coal requires more care than ordinary timber drawing, inasmuch as the object is not only to draw the props, but also to get out as much coal as possible.

96. Methods of Drawing.—Timber is drawn in several ways. The tools and appliances used for this purpose are

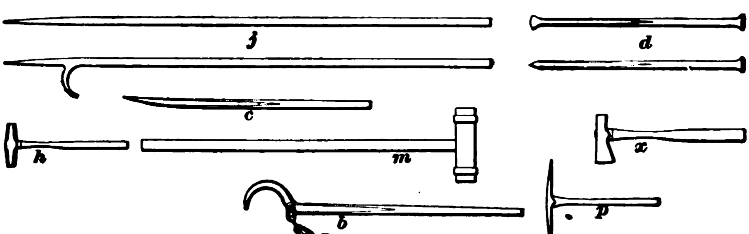


FIG. 60

shown in Fig. 60. The first thing to be done in drawing a prop is to loosen it at the top or bottom, depending on which point is the more accessible and the ease and convenience with which the work can be accomplished, by means of a pick *p*, crowbar *c*, or drill *d*. With a comparatively safe roof, the prop is knocked out with a hammer *h* or a maul *m* after all loose pieces have been carefully removed. Where the top cannot be depended on, the workman jumps back immediately after the blow is delivered on the head of the prop. The blows are repeated until the prop falls, but between blows the workman waits and listens for a sign of the roof giving way. When the prop falls, one of the workmen promptly sticks his pick *p* or jabber *j* into it and drags it out, without having to go under that portion of the roof from which the support has just been removed. In many cases, the prop, after having been loosened with a pick, is loosened still further by hammering, after which a dog and chain *b* are applied from another prop, at a safe distance, and the prop pulled out with safety, as shown in Fig. 61.

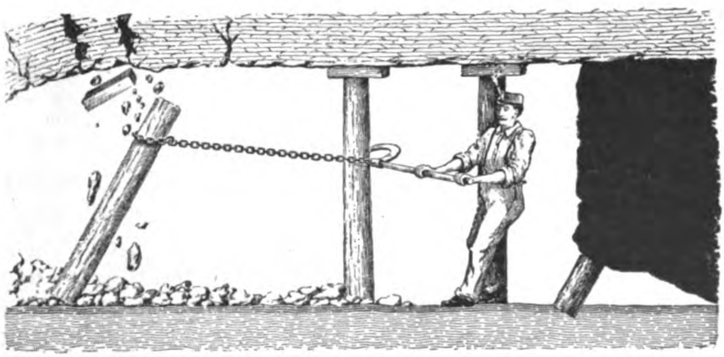


FIG. 61

97. When the foot of the prop is inaccessible or the post is heavily weighted, it is cut with an ax *x*, Fig. 60. This is a dangerous practice, especially in thick seams, and quite unnecessary, because the work of "throwing" the props can be done safely and in a thorough manner by boring a shallow hole in the prop with an auger and inserting therein 1 inch of a stick of dynamite, by which the prop is broken up.

In cases where only the head of the prop is accessible, a dog and chain are applied to it in such a way as to draw it up. The chain is thrown around the prop and forms a noose, as shown in Fig. 61; to the other end of the chain, the dog is fastened and placed against a prop near the one that it is intended to draw. The grip of the chain tightens as the force is applied to the dog and the post is loosened as shown.

98. An additional help in use at some collieries is shown in Fig. 62. It consists of a rope 7 yards long, with a hook attached to it. The end with the hook is lashed around the

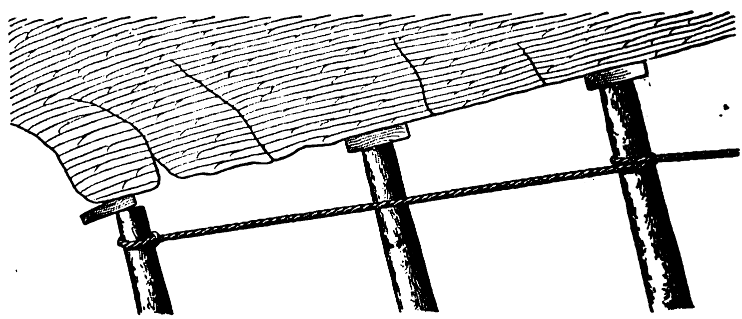


FIG. 62

prop that is to be drawn, and the other end is securely fastened to a firmly set prop some distance away. After the prop has been sufficiently loosened, or while it is being hammered, or while the dog and chain are being applied, a sudden jerk, produced by one or two men throwing their weight on the tightened rope near its middle point, will greatly help to loosen the prop and enable the men to drag it out immediately and with safety.

TAKING TIMBER INTO A MINE

99. Lowering Timbers Down a Shaft.—Timbers are usually taken down the shaft or slope on the carriage or slope car, unless they are too long to be thus handled; and in that case special devices are used. It is not safe to lower a timber down the shaft or slope when it is held merely by a rope hitch, since rope hitches are apt to slip and the timber to catch in the side of the opening.

When the timbers cannot be taken down on the carriage, they are frequently suspended beneath the carriage; and for this purpose there are a number of devices used.

Fig. 63 shows a clevis used for this purpose. A hole is bored through the timber about 1 foot from the end, and through this and the eyes in the clevis a bolt is run. A nut is screwed on to one end of the bolt and the clevis and stick are suspended from beneath the cage, or from a hook in the hoisting rope if no cage is used. A short piece of rope is spiked to the lower end of the timber so that the log can be steadied before lowering and can be drawn into the level at the bottom of the shaft.

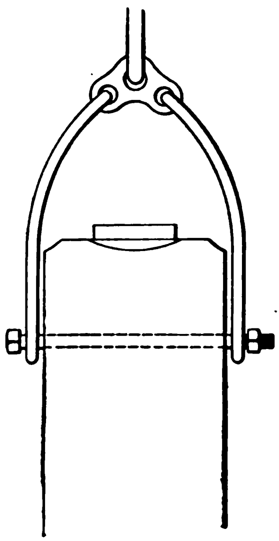


FIG. 63

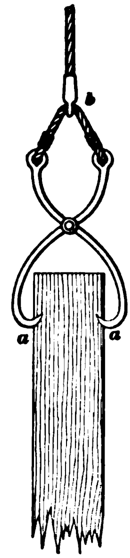


FIG. 64

100. Timber Tongs.—Sometimes, in place of a clevis and bolt, tongs, Fig. 64, are used. These are made with sharp points like ice hooks and have their points driven into the log on each side at *a*. These tongs are attached to the cage or rope by the eye *b* in lowering. The weight of the log causes the tongs to grip the log firmly, but there is danger of the log getting away unless a guide rope is employed in raising it from the ground and great care is taken. Another method employed is to use tongs having horizontal teeth that clasp the log and prevent its slipping. As additional security against slipping when such tongs are used, a hole through which to drive a good-sized spike into the log should be made in each tong.

101. Rope Knots.—Some timbermen are able to tie rope to logs so that the logs do not slip; it is, however, dangerous practice to attempt to prevent a log from slipping with a knot made by inexperienced persons. Fig. 65, *a*, shows a carpenter's knot which is fairly safe, but the loose end *b* should be marlin wound and spiked to the stick. The timber hitch and loop, shown at *c*, if properly made, is also good, since it offers two surfaces against slipping, but the hitch and loop should be spiked to the timber for greater security. The objection to rope knots, besides slipping, is that the timber does not hang vertically

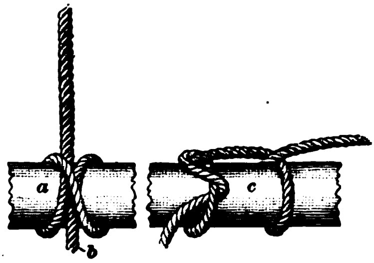


FIG. 65

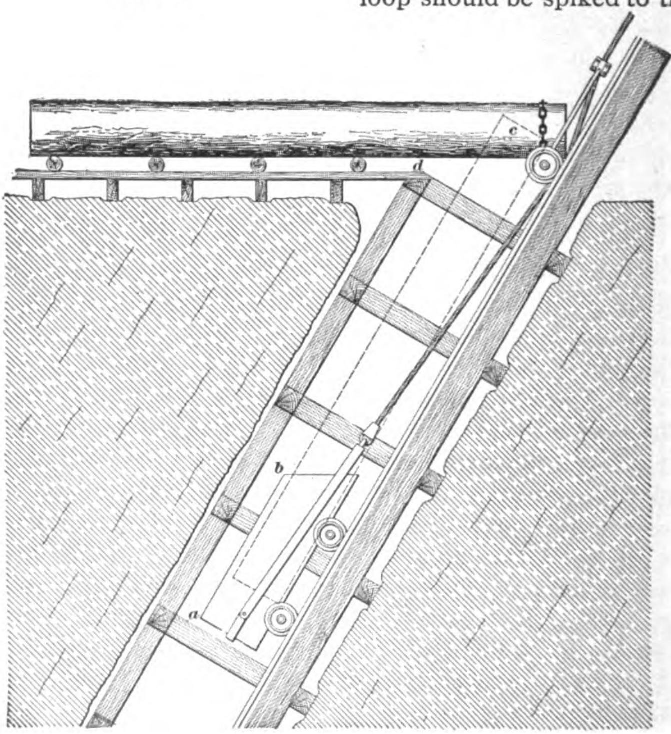


FIG. 66

in the shaft, and, owing to the twist in the rope, is apt to wind, unwind, and swing. For this reason, and because knots are not easily made, old, dry, pliable ropes are preferable to new or wet, stiff ropes in making slings for lowering timbers into mines.

102. Lowering Timbers Down a Slope.—Where gunboats or skips are used for hoisting at mines, one method of lowering timber into the mine is shown in Fig. 66. The top *a b* of the timber skip is removed and two wheels on an axle, Fig. 67, are specially arranged with a clamp for grasping the hoisting rope. The timber is run on rollers over the slope mouth and chained to the axle of the wheels. The axle is then hoisted up the slope and carries the log with it, until the loose end of the log is nearly ready to drop into the skip. It is necessary to lower and steady the log into the skip by a rope, otherwise the skip will be damaged by the fall to the position *c*, Fig. 66, from the platform *d*. This arrangement is only needed for long, heavy timbers, for several ordinary timbers can be taken down a slope in the skip without the use of the extra wheels.

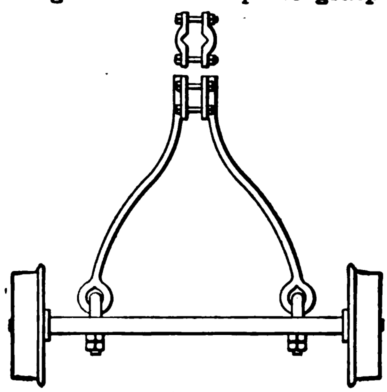


Fig. 67

103. Balanced Timber Skip.—At some coal mines, there is a special shaft or slope for use in taking timber, rails, and other supplies into the mines, so as not to interfere with the regular hoisting arrangements. The timber slope or shaft has a separate hoisting engine, or sometimes a special timber cage with a balance weight is provided, thus doing away with the use of a separate hoisting engine. The device is worked as follows: The cage or car filled with timber will descend and raise the balance weight. When the timber is unloaded in the mine, the balance weight will descend and raise the empty cage or car. The rope that is attached to the car and weight passes around a drum provided with a brake, and by means of this drum and brake the speed of hoisting or lowering is regulated.

When a flat car loaded with logs is let down a slope, the logs must be balanced and chained to the car so that they will not move in any direction. Particular care is needed if the slope is uneven, that is, changes its inclination, for timbers projecting over either end may strike the ground and cause the car to jump the track.

104. To Find the Longest Timber That Can Be Taken Down a Shaft and Into a Mine.—This is a problem

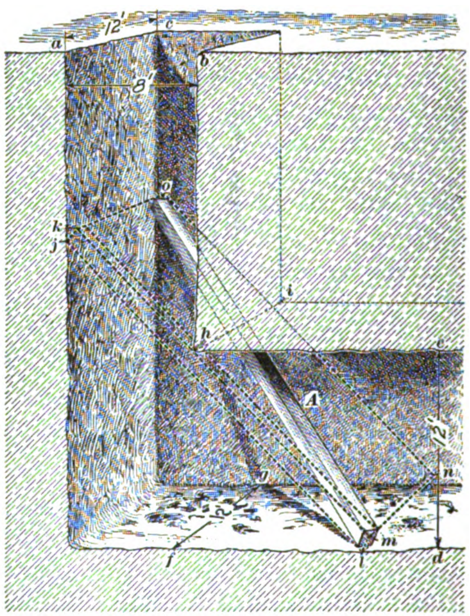


FIG. 68

that will probably come up sooner or later in connection with every shaft through which long timbers are taken into a mine, since the length of the rail or timber that can be taken into the mine depends on the size of the shaft. The simplest way to solve this problem is graphically, as shown in Figs. 68, 69, and 70, and as an illustration of the method to be used, the following example is given: The dimensions of a shaft are 8 ft. × 12 ft., and the gangway running at right angles with the shaft is 12 ft. × 12 ft.; assuming that the gangway is level, and the shaft vertical, what is the longest stick of timber 12 in. × 12 in. that can be taken down the shaft into the gangway?

The conditions of the problem are shown in Figs. 68 and 69. The width of the shaft, as *a b*, is 8 feet, *a c* is the length of the shaft (12 feet), and *d e* the height of the gangway (12 feet); *f g*, the width of the gangway (12 feet), equals *a c* the length of the shaft. The longest timber that can be taken into the mine is represented by *A*, extending diagonally across the shaft and gangway from the corner of the shaft farthest from the observer to the side of the floor of the gangway nearest the observer and just touching the line of intersection *h i* of the shaft and gangway. The rectangle *j k l m* represents the side of the longest timber that will pass from the shaft into the gangway in a direction parallel to the width of the shaft and the length of the gangway. The position and length of the longest stick that can be taken into the mine is determined graphically from the position *j k l m*, which is the projection of the stick *A* placed diagonally across the shaft and gangway.

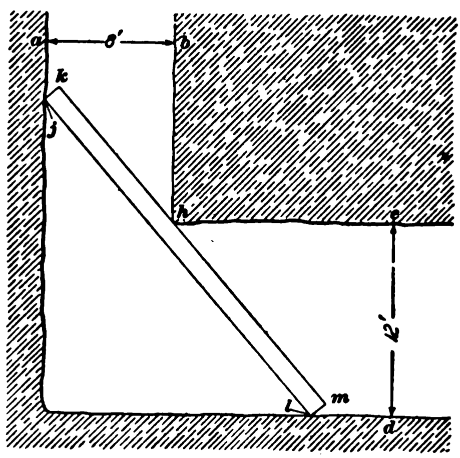


FIG. 69

To solve the problem, lay out, to scale, the side elevation of the shaft and gangway, as shown in Fig. 69; then cut a strip of cardboard, 1 foot wide, according to the assumed scale, so that *j k* equals 1 foot. The longest timber that can pass into the gangway from the shaft parallel with the width of the shaft may be determined by laying this strip of cardboard on the diagram and finding the longest length *k m* that can be made to pass the corner *h* without bending. Next measure *k m*, and with this length as one side and the length of the shaft (12 feet) as the other, *k o*, construct the rectangle *k m n o*, Fig. 70. This rectangle represents *k m n o*, Fig. 68. In this rectangle, try, diagonally, a strip of cardboard, cut 1 foot wide according to the assumed scale, and find the greatest length that can be placed diagonally, as shown in Fig. 70. By measuring this according to the adopted scale, the length of the longest stick of timber will be determined; in this case, it is 27.93 feet.

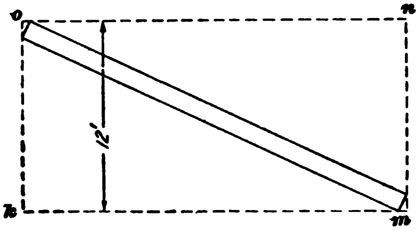


Fig. 70

TIMBER TREES

PRINCIPAL TIMBER TREES OF THE UNITED STATES

CONIFER WOODS

1. The greater part of all the lumber and timber used at the present time in the United States is obtained from the **conifers.** Conifers are an order of resinous trees, mostly evergreens with needle-shaped leaves and bearing cones; their wood is uniform in structure, generally light in weight, soft, stiff, and easily worked. Conifers in suitable dimensions for mine timbers are abundant in nearly every part of the United States and Canada, although the most valuable species are fast disappearing before the ax of the timberman.

The timber from the conifers, as a class, is frequently called soft-wood timber, though certain varieties of these timbers are subdivided into hard and soft varieties by lumbermen. Thus, there is hard pine and soft pine, though the pines as a class belong to the soft woods.

The principal varieties of conifers used for timber purposes are *cedar*, *cypress*, *fir*, *hemlock*, *pine*, and *spruce*.

CEDARS

2. Properties.—The wood of the **cedar tree** is light in weight, soft, stiff, of fine texture, but, with the exception of the redwood of California, it is not strong. The sap wood and the heart wood are distinct, the former being of a lighter color than the latter, which is dull grayish brown or red, usually the latter when properly seasoned. The principal species are *white cedar*, *canoe cedar*, *red cedar*, and *redwood*.

3. Varieties.—White cedar occurs in five varieties. (1) One variety grows from Maine to Minnesota and northward, scattered along streams and lakes, and frequently covering extensive swamps. This variety rarely grows large enough for timber but when large enough it makes excellent posts and ties, being very durable. (2) A medium-sized white cedar grows along the Atlantic and Gulf Coasts from Maine to Mississippi. (3) Along the Pacific Coast line of Oregon, there is a large white cedar that is cut extensively for lumber as it is heavy and strong; it is known as *Port Oxford cedar*, *Oregon cedar*. *Lawson's cypress*, and *ginger pine*. (4) Another variety, termed *incense cedar*, is a large tree abundantly scattered among the pine and fir trees of the Cascades and Sierra Nevada Mountains of Oregon and California. (5) *Canoe cedar* is classed as a white cedar, although it is the red cedar of the West. It is a very large tree that grows in swamps and along watercourses in Oregon, Washington, Northern California, and eastward to Montana. It is an important timber tree.

4. The **red cedar** is the most widely distributed conifer of the United States and occurs from the Atlantic to the Pacific Ocean, but attains a suitable size for lumber only in the Southern, and more especially in the Gulf, States. The heart wood of this species is red, while the heart wood of white cedar is grayish brown when first cut.

5. The **redwood** is the California "big tree" and is limited to the coast ranges of California, where it formed forests that are rapidly being converted into lumber. It has a narrow whitish sap wood, and light-red heart wood, but the latter soon turns to brownish red when exposed.

CYPRESS

6. Properties.—In appearance, quality, and usefulness, the **cypress** is similar to white cedar. It is a large deciduous tree, that is, one that sheds its leaves in season, occupying much of the swamp and overflow land along the coast and rivers of the Southern States. It is an exceedingly useful timber tree both for carpentry and mining purposes. Water tanks and shingles made from this wood are very durable.

There are four varieties of cypress known as *bald*, *black*, *white*, and *red cypress*. Black cypress and white cypress are heavy and light forms of the same species.

FIR

7. Properties.—The **fir** grows in the West with one exception, the Balsam fir. The name fir is frequently applied to spruce and, in the English market, to pine, but the fir is easily distinguishable from spruce, pine, and larch by the absence of resin ducts. The principal varieties are *balsam fir*, *white fir*, and *red fir*.

8. Balsam fir is a medium-sized tree that is scattered throughout the northern pine forests from Maine to Minnesota. It is cut, whenever of sufficient size, and sold with pine and spruce.

9. The **white fir** forms an important part of most of the western mountain forests and, in the vicinity in which it grows, furnishes much of the lumber. Medium-sized trees grow from Vancouver to California and eastward to Montana; large-sized trees are found from Oregon to Arizona, and eastward to Colorado and New Mexico. Good-sized trees often form extensive forests in the Cascade Mountains of Washington and Oregon.

10. Red fir, with white fir, forms extensive forests on the slope of the Cascade Mountains of Oregon at an elevation of from 3,000 to 4,000 feet above sea level. At times this tree becomes very large. Forests of red fir occur about the base of the Sierra Nevada Mountains of California and extend from Mount Shasta southward. This wood is not to be confounded with Douglas spruce, which is a kind of spruce that is sometimes called red or yellow fir.

HEMLOCK

11. Properties.—The wood of the **hemlock** is soft, stiff, brittle, cross-grained, rough, and splintery; with sap wood and heart wood not well defined. Hemlock wood is of a light reddish-gray color, comparatively free from resin ducts. It shrinks and warps considerably, and is principally used for sawed timber and timbers that are not to be exposed. For mine timber, it has not much value in the East, but it is claimed that the hemlock of the West is superior in weight, hardness, and durability. The hemlocks of the East are medium- to large-sized trees commonly scattered among broad-leaved trees and conifers, but often forming forests of almost pure growth. They are found from Maine to Wisconsin, and follow the Alleghanies to Alabama. Large-sized hemlock trees grow in Washington and California and eastward to Montana.

LARCH

12. Properties.—The **larch** is known as **tamarack** in Washington, Oregon, and Montana, where it grows to a large size. In the East, tamarack is known as **hackmatack** and is only a medium-sized tree that is found growing mainly in swampy land from Maine to Minnesota and southward to Pennsylvania. The wood resembles spruce in structure, but is more durable and approaches, in usefulness and quality, the best hard pines. The larches are deciduous trees that usually are found scattered among conifers.

PINES

13. Properties.—Pine wood is very variable, being light and soft in *soft pine*, such as white pine; of medium weight to heavy and quite hard in *hard pine*, of which the long-leaved, or Georgia, pine is the extreme form. Usually it is stiff, quite strong, of even texture, and more or less resinous. The sap wood is yellowish white; the heart wood, orange brown. Pine shrinks moderately, seasons rapidly and without much injury; it works easily; is never too hard to nail (unlike oak or hickory); is generally quite durable; and, if well seasoned, is not subject to the attacks of boring insects. The heavier the wood, the darker, stronger, and harder it is and the more it shrinks and checks. Pine is used more extensively than any other kind of wood. It is the principal wood in common carpentry, as well as in all heavy construction, such as bridges and trestles, about mines. Pine trees are usually large with few branches, the straight cylindrical, useful stem forming by far the greater part of the tree; they form vast forests, a fact that greatly facilitates their exploitation.

14. Varieties.—There are many varieties of pine and many special terms applied to pine timber denoting difference in quality, although in many cases these are largely local distinctions.

The principal species of pine are: *white pine*, *sugar pine*, *yellow pine*, *long-leaved pine*, *short-leaved pine*, *bull pine*, *loblolly pine*, *Norway pine*, *Cuban pine*, and *pitch pine*. Pines are frequently classed as soft and as hard pines.

Soft Pine.—The term *soft pine* on the Pacific Coast refers to the sugar pine, but in the East it refers to white pine alone.

White pine, variously known as pumpkin pine and soft pine, has been the most important wood in the Union, but it is now becoming quite rare. In the East, it grows from Minnesota to New England, and along the Alleghanies to Georgia, where it is a large-sized tree. On the eastern Rocky

Mountain slopes, from Montana to New Mexico, it is a small tree that forms forests of considerable extent. In Montana and the Pacific States, especially in Northern Idaho, the tree attains large size.

Sugar pine is a very large and important lumber tree in Oregon and California, where, with the white fir, it forms extensive forests.

15. Hard pine is a common term in carpentry and applies to everything of the pine species except white and sugar pines.

Yellow pine is a name applied, in trade, to all the southern lumber pines; in the northeastern part of the United States it is applied to pitch pine; in the West, it refers mostly to bull pine.

Long-leaved pine, known as *Southern yellow pine* and *Georgia pine*, forms extensive forests and furnishes the hardest and strongest pine lumber in the market. It grows to a large size on the Atlantic Coast from North Carolina to Texas, and may be distinguished from other pines by its clusters of three leaves, the leaves being from 10 to 15 inches long.

Short-leaved pine, known as *slash pine*, *Carolina pine*, *old field pine*, *yellow pine*, *Northern yellow pine*, *bull pine*, is the common lumber of Missouri and Arkansas. It may be distinguished from the long-leaved pine by its leaves being in clusters of two and only from 3 to 5 inches long. The tree resembles loblolly pine, and its wood the Norway pine.

Bull pine, or Western yellow pine, is a medium- to large-sized tree that forms extensive forests in the Pacific and Rocky Mountain regions. When its sap wood is wide, the wood varies in strength and durability, although one species, known as *black pine*, in California is quite hard. Bull pine furnishes most of the pine lumber of the West.

Loblolly pine, also known as *slash pine*, *old field pine*, *rosemary pine*, *sap pine*, *short-straw pine*, etc., is a large-sized tree that forms extensive forests. It has slender light-green leaves 6 to 10 inches long that are in clusters of three. It has wider ringed, coarser, lighter, and softer wood, with more sap wood than the long-leaved pine with which it is sometimes confounded. This is the common lumber pine from Virginia to South Carolina and is found extensively in Arkansas and Texas.

Norway pine is the common red pine found scattered in groves with white pine in New England, Pennsylvania, Minnesota, and Michigan. The sap wood is predominant and hence the lumber is not very durable.

Cuban pine grows along the coast from South Carolina to Louisiana and is known as *slash pine*, *swamp pine*, and *meadow pine*. It resembles long-leaved pine, but commonly has wider sap wood and coarser grain.

Pitch pine grows along the coast from New York to Georgia and along the mountains of Kentucky; its leaves are in clusters of three and are 3 to 5 inches long. The term pitch pine includes all Southern pines, and is especially applied to long-leaved pine in foreign markets.

SPRUCE

16. Properties.—**Spruce** resembles soft pine, as the wood is light, soft, stiff, and moderately strong, but has less resin than pine. Spruce has no distinguishing heart wood and both sap and heart wood are whitish. Spruces, like pines, form extensive forests, but they seem to thrive on thinner soils. The terms black spruce and white spruce, usually refer, respectively, to the narrow- and wide-ringed forms of the black spruce.

17. The **black spruce** is a medium-sized tree that occurs in forests and in groves in the lowlands and prairies of the United States from North Carolina to British Columbia.

18. White spruce is generally associated with black spruce and is most abundant along streams and water-courses. It grows largest in Montana and forms the most important tree of the subarctic forests of British Columbia. A medium-sized to large-sized white spruce forms extensive forests at elevations of from 5,000 to 10,000 feet above sea level in the Rocky Mountains from Montana to Mexico.

19. Douglas spruce is one of the largest and most important trees in the Western United States. In the Pacific States, it attains a diameter of 15 feet and also a fair size in the mountains of Colorado up to an altitude of 10,000 feet above sea level. It is variously known as *red fir*, *yellow fir*, and *Oregon pine*. When the wood is coarse-grained, heavy, hard and strong, with pronounced summer wood, it receives the name of *red fir*, but if it is fine grained and light, it is termed *yellow fir*. It is an excellent substitute for hard pine, and is especially suited to heavy construction.

BROAD-LEAVED TREES

DECIDUOUS TREES

20. The **hardwoods** are of complex and variable structure and therefore differ widely in quality. With the exception of oak, and possibly chestnut and locust, they do not make so good timbers for mine excavations as the conifers, but there are many places about mines where they are very useful.

The principal hardwoods are *ash*, *basswood*, *beech*, *birch*, *cherry*, *chestnut*, *elm*, *gum*, *hackberry*, *hickory*, *locust*, *maple*, *mulberry*, *oak*, *persimmon*, *poplar*, *cottonwood*, *sycamore*, and *walnut*.

ASH

21. Properties.—Ash is a heavy, hard, strong, stiff, and tough wood. Although the timber is straight grained and of coarse texture, it is not durable in mines or in contact with the soil. It is useful in the construction of cars, wagons, and chutes. Some species of ash are quite rapid growers and have stout trunks.

The principal species are *white ash*, *red ash*, *black ash*, *green ash*, and *Oregon ash*.

22. White ash is best developed in the Ohio River Basin.

Red ash is a small-sized tree that grows east of the Mississippi.

Black ash, also known as hoop ash and ground ash, is common from Maine to Minnesota and southward to Alabama.

Green ash grows from New York to the Rocky Mountains and southward to Florida and Arizona.

Western Washington and California have a medium-sized tree called *Oregon ash.*

BASSWOOD

23. Basswood is a medium-sized tree common in all forests of broad-leaved trees throughout the Eastern and Northern United States. It is also known as the *lime tree, American linden, lin,* and *bee tree.* The wood shrinks considerably in drying, but is light, soft, stiff but not strong, of fine texture, and white to light-brown color.

BEECH

24. Properties.—The wood of the beech tree is heavy, hard, stiff, strong, of rather coarse texture, white to light brown, not durable in the ground, and subject to boring insects. It shrinks and checks considerably in drying, but will be found useful for chutes as it wears smooth.

Beech is a medium-sized tree sometimes forming forests in the Mississippi Basin, but is also abundant from Wisconsin to Maine and southeast to Florida.

Blue beech, also known as *hornbeam, water beech,* and *ironwood,* is a small tree found in the Eastern United States, but attains its largest growth in the Southeast.

BIRCH

25. Species.—The **birches** are medium-sized trees that form extensive forests; they occur well scattered in all forests of broad-leaved trees in the United States. The wood is heavy, hard, strong, of fine texture, but shrinks considerably in drying and is not durable if exposed.

The sap wood is whitish and the heart wood shades from yellow to brown and red. The species vary in regard to names, which makes their description somewhat confusing.

Cherry birch is a medium-sized tree known also as *black birch*, *sweet birch*, and *mahogany birch*.

Yellow birch is a common medium-sized tree sometimes called *gray birch*.

Red birch, or river birch, is found from New England to Texas; it is lighter in weight than the preceding.

Canoe birch, also known as *white birch* and *paper birch*, is a small tree that grows along the northern boundary of the United States from the Atlantic to the Pacific.

CHERRY

26. Cherry wood is heavy, hard, strong, of fine texture, but better suited for decorative and finishing lumber than for mines, although it is sometimes useful for the latter purpose. The species are known as *wild cherry*, *black cherry*, *hawthorn*, and *wild apple*.

CHESTNUT

27. Properties.—The wood of the **chestnut,** while light and not strong, is stiff and of coarse texture, and very durable in contact with earth. Confined in the mine, it is not durable even when well seasoned, unless it is kept in a uniform condition of wetness or dryness.

28. Horse chestnut, or buckeye, grows in the Alleghanies and from Pennsylvania to Indian Territory. The wood is light, soft, and while not strong is of uniform texture and often quite tough. It is not used in mining except for temporary purposes.

ELM

29. Properties.—The wood of the **elm tree** is heavy, strong, hard, tough, and moderately durable in contact with the soil; it is commonly cross-grained, difficult to split and shape, and warps and checks considerably in drying, but stands well if properly handled. The broad sap wood is whitish, the heart brown, both with shades of gray and red. Split surfaces have a rough coarse to fine texture. Elm lumber is used in the construction of cars, wagons, etc. Elms are medium- to large-sized trees, with stout trunks, of fairly rapid growth, and while they do not form separate forests they are scattered in all the forests of broad-leaved trees of the United States, sometimes forming a considerable portion of the timber.

30. The varieties of elm are:

White elm, or American elm, which is a large-sized tree.

Rock elm, cork elm, hickory elm, or **cliff elm,** which is found westward from Vermont to Iowa as a medium-sized tree.

Red elm, slippery elm, or **moose elm,** which is a small tree found chiefly along watercourses.

Cedar elm, which is a small-sized tree quite common in Arkansas and Texas.

Winged elm, or **Wahoo,** which is a small common tree in Arkansas, Missouri, and Eastern Virginia.

GUM

31. The general term **gum tree** refers to two kinds of trees usually distinguished as *tupelo*, *sour*, or *black gum*, and *sweet* or *red gum*, the latter being a relative of the *witch-hazel*, while the former belongs to the *dogwood* family.

32. **Tupelo, sour gum,** or **black gum,** grows from Maine to Michigan, and southward to Florida and Texas. The wood is heavy, hard, strong, tough, of fine texture; frequently cross-grained; of yellowish- or grayish-white color; hard to split and work; troublesome in seasoning, as it warps and checks considerably; and is not durable if exposed. The trees are either medium- or large-sized with straight trunks; locally quite abundant; it never forms separate forests. The variety of tupelo gum known as *cotton gum* grows in the lower

Mississippi Basin, northward to Illinois and eastward to Virginia; otherwise it is like the preceding species.

33. Sweet gum, red gum, liquidambar, or **bilsted,** has a heavy, soft, stiff, strong wood that is tough, commonly cross-grained, and of fine texture. The broad sap wood is whitish, the heart wood reddish brown. This wood shrinks and warps considerably, but does not check badly and stands well when fully seasoned. Large-sized trees are abundant and are often the principal trees in the swampy parts of the bottoms of the lower Mississippi Valley, although they occur from New York to Texas and from Indiana to Florida.

HACKBERRY

34. Hackberry, or **sugar berry,** is a handsome, heavy, hard, strong wood, quite tough, of moderately fine texture, and greenish or yellowish-white color. It shrinks moderately; it is a medium- to large-sized tree that becomes largest in the lower Mississippi Valley, although it occurs in nearly all parts of the Eastern United States.

HICKORY

35. Properties.—The wood of the **hickory tree** is very heavy, hard, and strong, proverbially tough, of rather coarse texture, smooth, and of straight grain. The broad sap wood is white, the heart wood reddish nut-brown. Hickory dries slowly, shrinks and checks considerably, is not durable in the ground or if exposed. The sap wood, especially, is always subject to the inroads of boring insects. Hickory is used extensively in the manufacture of implements and machinery, for tool handles, etc. The hickories are tall trees with slender stems that never form more than small groves. The trees usually occur scattered among other broad-leaved trees in suitable localities. The following varieties contribute more or less to the hickory of the markets.

36. Varieties. — **Shagbark hickory,** or **shellbark hickory,** is a medium- to large-sized tree. It is the favorite among hickories and attains its best development in the Ohio and Mississippi basins, from Lake Ontario to Texas, and from Minnesota to Florida.

Mockernut hickory is termed in places *black hickory*, *bull and black nut*, *big bud*, and *white-heart hickory*. This is a medium- to large-sized tree, with the same range as the foregoing and is especially common in the South.

Pignut hickory, brown hickory, black hickory, or **switch-bud hickory,** is a medium- to large-sized tree, abundant in the Eastern United States.

Bitternut hickory, or **swamp hickory,** is a medium-sized tree, favoring wet localities, with the same range as the preceding.

Pecan, or **Illinois nut,** is a large hickory tree, very common in the fertile bottoms of the western streams. It grows from Indiana to Nebraska and southward to Louisiana and Texas.

LOCUST

37. Black locust, or **yellow locust,** has a very heavy wood that is hard, strong, and tough, of coarse texture, very durable in contact with the soil, shrinks considerably, and suffers in seasoning. Its very narrow sap wood is yellowish; the heart wood, brown, with shades of red and green. This tree is useful for wagon hubs and treenails but especially for ties, props, etc. It is a small to medium-sized tree, at home in the Alleghanies, and is being extensively planted, especially in the West.

38. Honey locust, sweet locust, or **three-thorned acacia,** has a heavy, hard, strong, tough wood of coarse texture. The narrow sap wood is yellow, the heart wood brownish red. So far, it has been but little appreciated except for fencing and fuel, and to some extent for wagon hubs and in rough construction. It is a medium-sized tree, found from Pennsylvania to Nebraska and southward to Florida and Texas; it is locally quite abundant.

MAPLE

39. Properties.—The wood of the **maple tree** is heavy, hard, strong, stiff, tough, and of fine texture; frequently wavy grained, giving rise to *curly* and *blister* figures. It is not durable in the ground or when otherwise exposed. Maple is creamy white with shades of light brown in the heart; it shrinks moderately; seasons, works, and stands well; wears smoothly, making it useful for chutes and car bodies. The maples are medium-sized trees, of fairly rapid growth. Sometimes they form forests and frequently constitute a large proportion of other groves. The following are the common varieties of maple.

40. Varieties of Maple.—**Sugar maple,** also known as *hard maple* or *rock maple,* is a medium- to large-sized tree; very common from Maine to Minnesota, and with birch sometimes forms groves in parts of the pineries; it extends southward to Northern Florida, but is most abundant in the region of the Great Lakes.

Red maple, swamp, or water, maple, is a medium-sized tree, but scattered along watercourses and other moist localities.

Silver maple, or **soft maple,** is a medium-sized common tree whose wood is lighter, softer, and inferior to hard maple. It grows best in the valley of the Ohio, but occurs from Maine to Dakota and southward to Florida.

Broad-leaved maple is a medium-sized tree that occurs on the Pacific Coast. It is a lighter, softer, and less valuable wood than hard maple.

MULBERRY

41. The **red mulberry tree** has moderately heavy, hard, strong, durable and rather tough wood of coarse texture. The sap wood is whitish; the heart, yellow to orange brown. The wood shrinks and checks considerably in drying, but works and stands well. The trees are common in the Ohio and Mississippi valleys, and are widely distributed in the Eastern United States, but have small size.

OAK

42. Properties.—Oak wood is variable in its physical properties; usually it is heavy and hard; very strong and tough; porous, and of coarse texture; the sap wood whitish, the heart wood brown to reddish brown. It shrinks, warps, and checks badly, giving trouble in seasoning, is durable, and little subject to the attacks of insects. Oak is used for many mining purposes, and for heavy construction. The trees are of medium to large size and form the predominant parts of many forests.

43. There are more than fifty varieties of oak. Three well-marked kinds, *white*, *red*, and *live oak*, are distinguished and kept separate in the market. Of the two principal kinds, white oak is the stronger, tougher, less porous, and more durable. Red oak is usually of coarser texture, more porous, often brittle, less durable, and even more troublesome in seasoning than white oak. The red oaks everywhere accompany the white oaks, and like the latter are usually represented by several species in any given locality. Live oak, once largely employed in shipbuilding, possesses all the good qualities of white oak, except that of size, and even to a greater degree. It is one of the heaviest, hardest, and most durable building timbers of the United States; in structure, it resembles the red oaks, but is much less porous. Trees of upland growth are better than those that grow in wet places on account of their slower growth and smaller cell structure. The following are the common varieties of oak.

44. Varieties.—White oak is a medium- to a large-sized tree that is common in the Ohio and Mississippi valleys, and throughout Eastern United States. White oak is a medium- to small-sized tree in Texas and eastward to Alabama, but of medium to large size on the Pacific Coast from

Washington to California, and is the largest oak on the Pacific Coast.

Bur oak, mossy-cup oak, or over-cup oak, is a large-sized tree that is abundant in the bottoms west of the Mississippi, and that ranges farther west than the white oak.

Swamp white oak is a common large-sized tree that grows most abundantly in the Lake States, but which occurs in the same localities as the white oak.

Yellow oak, chestnut oak, or chinkapin oak, is a medium-sized tree found in the Southern Alleghanies and eastward to Massachusetts.

Basket, or **cow oak,** is a large-sized tree locally abundant in the lower Mississippi Valley and eastward to Delaware.

Post oak, or **iron oak,** is a medium- to large-sized tree that grows from Arkansas to Texas, eastward to New England, and northward to Michigan.

Red oak, sometimes called *black oak,* is a medium- to large-sized tree; common from Maine to Minnesota and southward to the Gulf of Mexico.

Black, or **yellow, oak,** is a medium- to large-sized tree; very common in the Southern States, but occurring as far north as Minnesota, and eastward to Maine.

Spanish oak, sometimes called *red oak,* is a medum-sized tree, common in the South Atlantic and Gulf region, but found from Texas north to Missouri and New York.

Scarlet oak is a medium- to large-sized tree best developed in the lower basin of the Ohio, but found from Maine to Missouri and from Minnesota to Florida.

Pine oak, swamp Spanish oak, or **water oak,** is a medium- to large-sized tree common along the borders of streams and swamps from Arkansas to Wisconsin, and eastward to the Alleghanies.

Willow, or **peach, oak,** is a small- to medium-sized tree growing from New York to Texas and northward in the Mississippi Valley as far as Kentucky.

Water oak, duck oak, possum oak, or **punk oak,** grows to a medium- or large-sized tree from the Gulf States, northward to Delaware, Missouri, and Kentucky.

Live oak is a small-sized tree scattered along the coast from Virginia to Texas.

Live oak, maul oak, or **Valparaiso oak,** is a medium-sized tree that grows in California.

PERSIMMON

45. The wood of the **persimmon tree** is very heavy and hard, strong, and tough. It resembles hickory, but is of finer texture; the broad sap wood is of a cream color, the heart black. It is a small- to medium-sized tree, common and best developed in the lower Ohio Valley, but occurs from New York to Texas and Missouri.

COTTONWOOD AND POPLAR

46. Properties.—**Cottonwood, poplar, tulip,** and **cucumber trees** are often confounded on account of the close resemblance they bear to one other, but poplar and cottonwood are not so good wood as tulip and cucumber. The wood of cottonwood and poplar trees is light, soft, strong, of fine whitish, grayish, to yellowish color, usually with a satiny luster. It shrinks moderately, warps excessively, checks slightly, and is not durable. The following are the common varieties of cottonwood and poplar.

47. Varieties.—Cottonwood is a medium- to large-sized tree that forms forests of considerable size along many of the western streams, and furnishes most of the cottonwood of the market. It grows in the Mississippi Valley and west from New England to the Rocky Mountains and from Texas to California.

Balsam, or **balm of Gilead,** is a medium- to large-sized poplar tree, common all along the northern boundary of the United States.

Black cottonwood is the largest deciduous tree of the state of Washington, and is very common in the Northern Rocky Mountains and Pacific Region.

Poplar is a medium-sized tree, chiefly used for paper pulp. It grows from Maine to Minnesota and southward along the Alleghanies.

Aspen is a small- to medium-sized tree, often forming extensive forests and covering burned areas. It grows from Maine to Washington and northward and southward in the western mountains to California and New Mexico.

48. The tulip tree, known also as *yellow poplar*, is quite variable in weight, the wood being usually light, soft, stiff, but not strong, of fine texture and yellowish color. The wood shrinks considerably, but seasons without much injury; works and stands remarkably well. It is a large tree, does not form forests, but is quite common, especially in the Ohio Basin; occurs from New England to Missouri and southward to Florida. Does not last long in mines.

49. The cucumber is a medium-sized tree, most common in the Southern Alleghanies, but distributed from New York to Arkansas, southward to Alabama and northward to Illinois. The wood resembles tulip wood and is often confounded with it in the markets. Both trees have flowers; the latter is sometimes termed *magnolia.*

SYCAMORE

50. The tree known as the **sycamore, button-ball tree,** or **water beech,** has moderately heavy, hard, stiff, strong, tough wood that is usually cross-grained, of coarse texture, and white to light-brown color. The lumber is hard to split and work, shrinks moderately, warps and checks considerably, but stands well. It is a large tree of rapid growth, common and largest in the Ohio and Mississippi Valleys, but is at home in nearly all parts of the Eastern United States. The California species resemble in their wood the eastern tree.

WALNUT

51. Black walnut wood is heavy, hard, strong, of coarse texture, with whitish narrow sap wood and chocolate-brown heart wood. The lumber shrinks moderately in drying, but works and stands well. Walnut, which was formerly used even for fencing, has become too costly for ordinary uses and is today employed largely as a veneer for inside finish and cabinetwork; also in turnery for gunstocks, etc. Black walnut is a large tree, with stout trunk, of rapid growth, and was formerly quite abundant throughout the Alleghany region, occurring from New England to Texas, and from Michigan to Florida.

52. Butternut, or white walnut, has wood similar to black walnut. It is a medium-sized tree and not durable when cut and exposed.

TRACKWORK

INTRODUCTION

GENERAL CONSIDERATIONS

1. Advantage of Good Mine Tracks.—The opinion that anything is good enough for a mine track is incorrect, and although it is still held in practice by some, in the larger and more modern mines the construction and maintenance of the roadbed and track, particularly on the main entries of mines where mechanical haulage is used, receives as much care and attention as the track of a surface railroad. The reason for this is self-evident, for with a poor track heavier locomotives are required to haul a given load than on a good track thus necessitating a larger original investment, while the wear of the rolling stock and the cost of repairs are also increased. If the ties are not properly spaced and tamped; if the roadbed is not properly drained, graded and ballasted; if the rails are not properly spiked, lined, gauged, and leveled, trouble is sure to ensue. Where cars in good order jump the track or where the resistance to haulage is greater than it should be, the trouble can generally be traced to poor tracks. When cars jump the track, not only are the cars usually damaged, but time is wasted in putting them back on the track, the output is thus diminished, and the whole work of the mine is disarranged; there is also danger of the car runners being maimed or killed. When a coal mine has poorly constructed tracks, the cars are usually, also, in bad order and a large scrap pile containing broken car irons, bent axles, and discarded wheels is found. There is no doubt but that, among the numerous items that make up the cost of mining, that of haulage is as essential and should be as carefully considered in attempting to decrease the cost of mining as any other item. The smooth running of the whole mine depends largely on the question of mine haulage.

2. Direction of Mine Road.—To insure a good mine road, the entry should be driven as straight as possible; and as far as practicable, the grade should be such as to favor the movement of the loaded cars. Uniform grades can seldom be obtained for the entire length of the haulage road, but the local grade should be made uniform even if it requires blasting top or lifting bottom. In flat coal deposits, the roads can generally be driven straight if care is taken in driving the openings; but in steeply inclined and irregular deposits it is frequently necessary to have the road follow the strike of the bed, thus necessitating curves. For haulage roads in such mines the curves cannot be determined until the excavation has been made, after which it may be found necessary to cut the rib or rock walls in order to put in proper curves.

3. Single or Double Track.—A haulage road may contain a single track laid with turnouts for the passing of the loaded and empty trips, or it may be double-tracked, one track being for the loaded and the other for the empty trip. Both tracks may be in the same entry if there is sufficient width, or where the conditions are such that a wide entry cannot be maintained, the tracks may be placed in parallel narrow entries. A double-track road is intended to provide for a large output, but with a proper system of turnouts the same output can be handled with less expense on a single track, but in this case closer supervision must be given to the haulage by the mine officials.

4. Differences in Mine Track.—The track in different parts of the mine is not uniform in construction; for instance, on the main haulage road, much longer trains are run than on the cross-roads, and at a much higher speed; the track on the main roads is, therefore, usually more substantially laid than that on the cross-roads. For a similar reason, the track on the cross-roads is much more substantially laid than the track in the rooms.

5. Main-Entry Tracks.—Since the traffic in coal mines is heaviest on the main entries, the rails should be heavier there than on the cross-entries, and special care should be given the roadbed. Where locomotives are used for haulage purposes, the rails should weigh from 40 pounds to 60 pounds per yard, and even heavier rails are sometimes used. In other systems of haulage, they should weigh not less than 30 pounds per yard to insure the best results, although lighter rails are often used, particularly where mules or horses are the motive power.

A rule given by some of the makers of electric locomotives is to allow 10 pounds of rail per yard for each ton of weight on each driver. Thus for a 4-wheel locomotive weighing 20 tons the rule would give $\frac{20}{4} \times 10 = 50$ pounds per yard.

EXAMPLE.—Calculate the weight of rail that should be used for a locomotive weighing 13 tons.

SOLUTION.—Assuming that there are four drivers and that each driver carries one-fourth the weight,

$13 \div 4 = 3.25$ T. on each driver; $10 \times 3.25 = 32.5$ lb. per yd. Ans.

This rule gives the minimum weight of rail recommended, and it is very common practice to use 40-pound rails on main roads for this weight of locomotive.

The cross-ties should be of hardwood wherever possible, have at least a 5- to 8-inch face and be 4 to 6 inches thick, and should be placed so that from the center of one tie to the center of the next the distance will not exceed 2 feet. The roadbed should be well drained, the ties of sufficient size and firmly tamped, and the rails laid in alinement.

6. Cross-Entry Tracks.—The traffic on cross-entries not being as great as on the main entry of a mine, the rails may be of lighter section, but rails weighing not less than 25 to 30 pounds should be used if motors are to run over them. The ties should be placed about 2 to 3 feet between centers and have at least a 4- to 6-inch face and be 4 to 5 inches thick. The tracks should be lined up and kept to grade by tamping under the ties. If only mules are used on the cross-entry, the ties can be given 30-inch centers if the rails are of 30-pound section, but if of smaller section the ties should be placed closer. There should be a ditch on the side of the track for drainage. This ditch should be kept free from rubbish to prevent the water from backing up under the roadbed, as that will soften when wet, so that the ties will sink or form low places when cars pass over them.

7. Room Tracks.—The track construction in most rooms in coal mines consists in spiking rails weighing from 16 to 25 pounds per yard to ties that have 3- or 4-inch faces and thickness enough to take the spike. The ties are placed 3 or 4 feet apart and tamped with gob. This flimsy arrangement of tracks is used because the tracks are removed as soon as the room is finished and moved elsewhere and all that is required of the rails is that they shall not spread and allow the cars to run off the track.

8. Wooden Tracks.—Formerly, wooden tracks were used extensively in mines, particularly for the rooms, but iron has now very largely replaced the wooden mine rail excepting for short distances at the faces of rooms and of entries to connect the face with the permanent track. Such track is also extensively used where the pillars are to be robbed and there is danger of a crush coming on that will cover the track and prevent its being used again. In these cases, the loss is not so heavy with wooden tracks as with iron or steel. Wooden rails are also of advantage on steep grades, as the cars can be more easily spragged.

Hard woods, such as oak, hickory, or maple, are used for wooden track, the timbers being cut in sizes 2 inches by 4 inches, or 3 inches by 4 inches, and from 8 to 24 feet in length. Soft wood or poorly seasoned wood is easily cut by the flanges of the car wheels. Badly shaped rails allow the wheels to climb the rails. The wooden rail is frequently nailed or spiked to the ties, but the rails are more likely to spread when thus fastened than when the ties are notched and the rails held in place by wedges, as shown in Fig. 1. In this figure, *A* is the tie; *B*, the rails; and *C*, the wedges holding the rails in the notches cut into the ties.

In order to protect the upper side of the rail and to reduce the friction, the upper face is frequently covered with a narrow strap iron. Wooden rails are sometimes also used

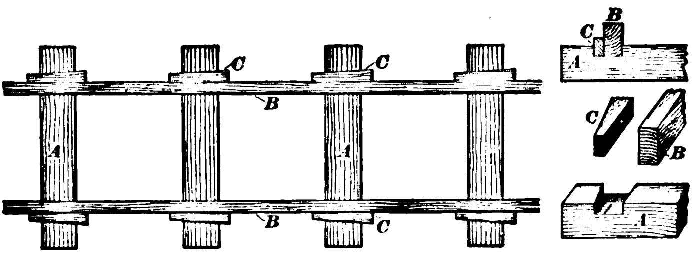


FIG. 1

in connection with iron rails on steep grades, the wooden tracking being laid against the outside of the iron rails and of the same height for the purpose of increasing the friction of the spragged wheel.

GRADES FOR MINE ROADS

9. Suitable Grades.—Where mine cars having capacities ranging from 1.5 to 2.5 tons of coal are hauled by animals, the grades should not exceed 2 per cent. and should favor the loaded cars. If the grade be less than 2 per cent., it will be better; but in every case the grade should be sufficient for drainage. While water will run on a light grade, in coal mines the grade should not be less than .5 per cent., because coal dust and coal falling from the cars will accumulate and possibly back up the water, necessitating frequent cleaning of the ditches where, on a steeper grade, ditches need not be cleaned except at stated intervals.

When hauling is done by locomotives, the average grade should not exceed 2.5 per cent. Since the tractive power of the locomotive is limited by the adhesion between the rails and the tires of the driving wheels, and this adhesion decreases as the grade increases, too great a percentage of the tractive power will be consumed in hauling the locomotive up the grade. The resistance offered to tractive power, due to gravity, increases with the steepness of the grade; and the resistance due to friction varies with the character and conditions of rolling stock and track.

10. Methods of Expressing Gradients.—The **percentage method** of expressing grades is generally adopted by engineers, as it states at once the number of feet rise per 100 feet of horizontal measurement, fractions of a foot being expressed in tenths and hundredths of a foot. Thus, a 1.5-per-cent. grade signifies that there is a rise of 1.5 feet in 100 feet measured horizontally. Upon a steep pitch the per cent. of grade is occasionally expressed in terms of the rise per 100 feet measured on the incline instead of horizontally. This method is misleading and should not be used.

American railroad engineers frequently express the grade as feet of rise in the distance of a mile; for example, 79.2 feet per mile. In order to reduce grades expressed in this manner to percentage grades, multiply the amount of rise in feet per mile by 100 and divide by 5,280. 79.2 feet per mile is, therefore, $\frac{79.2 \times 100}{5,280} = 1.5$ per cent.; or $79.2 \div 52.8 = 1.5$ per cent.

English engineers state, in feet, the distance in which the grade rises 1 foot. The expression 1 in 52.8 would therefore signify that there is 1 foot rise in 52.8 feet of length. To reduce such expressions to percentage grades divide 100 by the horizontal in which the rise is 1 foot, $100 \div 52.8 = 1.9$ per cent. grade. To reduce such a grade to feet per mile, divide 5,280, the number of feet in a mile, by the number of feet required for a rise of 1 foot, thus $5,280 \div 52.8 = 100$ feet rise per mile.

Grades are sometimes expressed in degrees, the angle that the incline makes with the horizontal being measured. This is an inconvenient method, as the rise of the grade is the tangent of the angle and requires the use of tables of natural functions to determine the amount of rise.

11. Determination of Grades.—Accurate elevations are taken as the road is advanced and a profile platted showing the rise and the height of the excavation between the floor and the roof. The elevations are also taken on cross-entries for 100 or 200 feet in order to bring them to a grade that will correspond with the main-entry grade where the switch is placed. Grades are deceitful, so that the engineer does not trust his eye, but depends on his instrument for measurements. Mine roads should be graded before the tracks are put down, because then the bottom can be lowered or lifted and at the same time the top can be taken down, if that is necessary to keep the area uniform and afford headroom, without the inconvenience or expense of doing the work when tracks are down.

The accurate method of measuring grades in mines is by the use of a mining transit or a Y level and rod; but for rough grade measurements, a straightedge 100 inches long may be held horizontally by means of an ordinary spirit level and the distance measured from the end that is off the ground to the ground. This distance, expressed in inches, is the per cent. grade.

GAUGE OF MINE TRACKS

12. Width of Gauge.—The **gauge** of a track is the distance between the inside edges of the heads of the rails. This gauge should conform to the conditions peculiar to the particular mine in question. The thickness of the seam and the character of roof and floor determine in a general way the size of the haulage roads, as explained in *Methods of Working*, and consequently of the mine cars that pass through them. The question of economical haulage considers a minimum number of cars having a maximum capacity. Since the car length is limited by the necessarily short wheel base to about 10 feet, and its height by the thickness of the seam and limit of easy hand loading, the remaining dimension or the width of the car is usually the variable factor.

To obtain the maximum capacity required, the width of the car must be increased, thereby requiring a broader gauge for stability. A broader gauge reduces wear and tear on tracks and rolling stock, and requires outside wheels, which are cheap, easy to lubricate, and easy to replace. Cars with a relatively narrow gauge run more easily around sharp curves, and they are generally made with inside wheels. With wheels inside the frame, the capacity of narrow-gauge cars may be made to almost equal that of cars of broader gauge, but they lack the stability of the latter. With narrow gauges, shorter ties can be used, reducing the amount of cutting in the bottom of a thin inclined seam, and leaving more room available for ditching and for gob room, but with a very narrow gauge too little room is given for the mules to tread, and they frequently slip on the rails or inclines and at curves.

The most common track gauges in coal mines are 30, 36, 42, and 48 inches, but these are not absolute, as smaller and larger gauges are often employed. Gauges less than 26 inches make the cars top heavy and gauges more than 48 inches require large curves and extra wide haulage ways, room necks, etc.

In proportioning the gauge of a track to a given width of entry, provision should be made, if possible, to allow for a passageway between the car and the ribs, or at least between the car and one rib, so that a man and a mule can pass between the car and the rib.

In laying a track to a certain gauge, a **track gauge** is used. Fig. 2 shows this tool made of 1-inch round iron *a* with lugs *b* and *c* welded near the ends. The distance shown from outside to outside of the lugs is the gauge of the track.

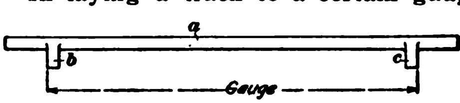


FIG. 2

An allowance of about ½ inch is made on a straight track between the wheel gauge of the car and the gauge of the track so as to avoid binding. A greater allowance is made on curves, the amount depending on the sharpness of the curve. The gauge should not be crowded when laying the track and should be placed a little ahead of the spiking, so as not to be hit by the hammers. The rails are brought to gauge before spiking, and just before the spikes are driven home the gauge is placed on the rails and again after they are spiked fast.

TRACK MATERIALS

TIES

13. Main-entry ties should have at least a 5- to 8-inch face, and be 4 to 6 inches deep; their length will depend on the gauge of the track, but they should project from 8 to 12 inches on each side of the rail to give the roadbed stability and the ties a resting surface for the transmission of weight to the roadbed. The wood of main-track ties should be chestnut, oak, or hard pine. Locust ties are very serviceable, but it is not probable that they can be had in sufficient numbers to meet the demand. In case the above woods are not to be had, other woods will naturally take their place, but if such is the case their faces should be enlarged. Sawed ties are not as durable as hewed ties with the bark removed.

On cross-entries where 20- to 30-pound rails are used, the ties may have a 4- to 6-inch face and be 4 to 5 inches thick. In rooms, the ties need only be faced 3 or 4 inches, or sufficient to form a flat surface for the rail to rest on.

14. Laying Ties.—Before the ties are put down, the roadbed should be surfaced and brought to grade. The center points should be put in place so that the ties should be nearly in the position they will occupy when the rails are spiked to them. Many lay the ties and the rails before the roadbed is surfaced and brought to grade; this method is not recommended except where surfacing material must be brought from a distance in cars, because the roadbed will not be as firm and will need attention until it has thoroughly settled.

15. If a fireclay bottom is wet, the ties sink into it; and if animals travel over such a roadbed, it soon becomes muddy and affords an insecure footing. Where depressions in the floor allow water to accumulate, this state of affairs is particularly apt to occur, so that especial attention should be paid to the ditching in order to drain off the water. If the water comes from the roof and drips on the track, the soft clay must be dug out and ashes substituted. The ashes may absorb the moisture and dry the fireclay to such an extent as to make the roadbed serviceable, but in case they do not, additional ties should be put in so that the ties are close together. If it is necessary to place the ties close together when the road is first laid, only a part of the ties are spiked to the rails until the track and bed have been put in shape; then the rails are spiked fast to the other ties. This forms a corduroy roadbed and will afford a fair roadbed and track, although it may need overhauling from time to time as the clay swells up and mixes with the cinders.

In some mines that have soft clay bottoms, it is the custom to lay mud-sills of 3″ × 12″ plank parallel with the track and on these to place the cross-ties. The planks are sometimes placed skin to skin; the same care, however, is necessary in this as in the former case to provide for drainage and to prevent the clay oozing up between the planks.

16. Spacing Ties.—The ties are supports for the rail, which acts as a beam supported at regular intervals and with a moving load on it. The moving load causes a much greater stress than a quiescent or dead load, and the rails bend as the cars move over them. The closer together the ties are placed the greater bearing surface do they furnish to the rails, and, therefore, the less bending is there of the rails and the less sinking of the track as a whole.

The ordinary spacing on main entries is from 18 inches to 2 feet, measured between the centers of the adjacent ties. In speaking of the spacing of ties, the distance between the edges of the ties is sometimes used instead of the distance between centers. Thus, if the ties have an 8-inch face and are spaced 2 feet from edge to edge, there will be $2\frac{2}{3}$ feet between the centers, which is too great a distance for a road-bed on which there is a heavy traffic, as the ties will be cut and the spikes loosened by heavy loads passing over them.

On cross-entries, a distance of $2\frac{1}{2}$ to 3 feet between centers is allowable where 30-pound rails are used. Ties for room track have a 3- to 4-inch face and sufficient thickness to take the spike, and are placed from 3 to 4 feet apart.

The ends of the ties should be lined up along one side of the track, so that they are the same distance from the rail. Each tie should be at a right angle to the rail on a straight track and on a curve along the radius of the curve.

17. The **number of ties** in any given distance depends on the distance they are placed from center to center. This being known and the cost of ties being known, that factor which enters into the cost of a roadbed can be calculated.

TABLE I

NUMBER OF TIES

Distance Center to Center Feet	Number of Ties per 100 Yards of Track	Number of Ties per Mile
$1\frac{1}{2}$	200	3,520
$1\frac{3}{4}$	172	3,017
2	150	2,640
$2\frac{1}{4}$	133	2,347
$2\frac{1}{2}$	120	2,112
$2\frac{3}{4}$	109	1,920
3	100	1,760

RAILS AND RAIL FITTINGS

18. Weight of Rails.—Rails should be purchased with reference to the position they are to occupy in the mine. Main entries should have heavier rails than cross-entries, and the cross-entries heavier than rooms where iron is used in rooms. The weights and dimensions of American rail sections up to 60 pounds per yard are given in Table II, also the tons of rails per mile of track.

TABLE II

RAILS

Weight per Yard Pounds	Width of Base and Height Inches	Width of Head Inches	Weight and Cost of Rails per Mile of Track			Weight and Cost per 100 Yards of Track		
			Tons	Pounds	Cost at $10 per Ton of 2,240 Pounds	Tons	Pounds	Cost at $10 per Ton of 2,240 Pounds
12	2	$1\frac{1}{8}$	18	1,920	$188.57	1	160	$10.71
14	$2\frac{1}{8}$	$1\frac{1}{4}$	22		220.00	1	560	12.50
16	$2\frac{1}{4}$	$1\frac{1}{4}$	25	320	251.42	1	960	14.29
18	$2\frac{3}{8}$	$1\frac{3}{8}$	28	640	282.85	1	1,360	16.07
20	$2\frac{1}{2}$	$1\frac{3}{8}$	31	960	314.28	1	1,760	17.85
25	$2\frac{3}{4}$	$1\frac{1}{2}$	39	640	392.85	2	520	22.32
30	3	$1\frac{5}{8}$	47	320	471.42	2	1,520	26.78
35	$3\frac{1}{4}$	$1\frac{3}{4}$	55		550.00	3	280	31.25
40	$3\frac{1}{2}$	$1\frac{7}{8}$	62	1,920	628.57	3	1,280	35.71
45	$3\frac{11}{16}$	2	70	1,600	707.14	4	40	40.17
50	$3\frac{7}{8}$	$2\frac{1}{8}$	78	1,280	785.71	4	1,040	44.64
55	$4\frac{1}{16}$	$2\frac{1}{4}$	86	960	864.28	4	2,040	49.11
60	$4\frac{1}{4}$	$2\frac{3}{8}$	94	640	942.85	5	800	53.57

19. In order to calculate the weight of rails required for a given length of road, the following rules for the long tons required per mile or per 100 yards may be used.

Rule I.—*To find the number of tons of rails required for 1 mile of track, multiply the weight per yard by 11 and divide the product by 7.*

Rule II.—*To find the number of tons of rails required for 100 yards of track, divide the weight per yard by 11.2.*

EXAMPLE 1.—How many tons of 35-pound rails will be required for 1 mile of track?

SOLUTION.— $\frac{35 \times 11}{7} = 55$ T. Ans.

EXAMPLE 2.—How many tons of 14-pound rails are required for 100 yards of track?

SOLUTION.—

$$\frac{14}{11.2} = 1.25 \text{ T., or 1 T. and 560 lb. Ans.}$$

20. Cost of Rails.—Rule I.—*To find the cost of rails required for 1 mile of track, multiply the cost of the rails for 1 mile of track at $10 per ton as given in Table II, by one-tenth the market price of the rails.*

Rule II.—*To find the cost of rails required for 100 yards of track, multiply the cost of the rails for 100 yards of track, at $10 per ton, as given in Table II, by one-tenth the market price of the rails.*

In purchasing rails, obtain, if possible, a price delivered at the mine, for rail mills sometimes obtain special freight rates, which purchasers cannot get.

EXAMPLE 1.—What will be the cost of 1 mile of 40-pound rails, when the market price of the rails is $30 per ton?

SOLUTION.—From Table II, the cost of 1 mile of 40-lb. rails at $10 per T. is given as $628.57. Hence,

$$\$628.57 \times \tfrac{30}{10} = \$1,885.71. \text{ Ans.}$$

EXAMPLE 2.—What will be the cost of 100 yards of 25-pound rails if the price is $28 per ton?

SOLUTION.—At $10 per ton, the cost of 100 yards of 25-pound rails is given in Table II as $22.32. Hence,

$$\$22.32 \times \tfrac{28}{10} = \$62.50. \text{ Ans.}$$

21. Track Joints.—Rails should have their joints broken, that is, the joint between two rails on one side of the track should not be opposite the joint between two rails on the other side of the track. Care should be taken when laying rails on the surface not to have the ends against each other but a little distance apart to allow for expansion, the distance depending on the variations of temperature. Underground there is little variation in temperature except near an intake, so little or no allowance is made in mines.

22. Fish-plates are flat metal plates placed on opposite sides of the rails at each joint and bolted to the ends of the two rails to hold them together firmly. Some think that because fish-plates are generally used ties are not necessary under a rail joint. It is best, however, to place a tie under each joint, even when angle fish-plates are used, since the bolts work loose and permit the ends of the rails to bend down.

Fish-plates are supplied with the rails and should fit the rails accurately. Their cost is separate from the rails, but they should be bought from the makers of the rails since different rail makers roll different rail sections and place the bolt holes in the rails to agree with their fish-plates. Two kinds of fish-plates are in common use—*strap fish-plates* and *angle fish-plates.*

Strap fish-plates are simply flattened bars of iron with holes punched through them for bolts. The holes are made somewhat larger than the bolt to permit of rail expansion and contraction. In ordering fish-plates, the exact location of the bolt holes must be specified as well as the distance of the holes from the ends of the plate, as shown by the dimensions *a*, *b*, *c*, and *d*, Fig. 3. One of the most disagreeable

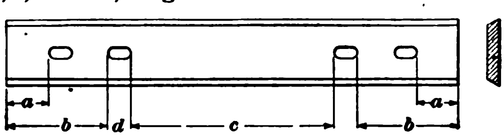


FIG. 3

features that trackmen have to contend with at mines is matching fish-plates, and the only possible way to avoid this is to specify the kind wanted, and have the rails punched to fit. The weight of the rail and if possible the section should be sent with the order. The section number and order can be had from the maker's bill if no section drawing is available.

The nuts on the fish-plate bolts will rust and will be difficult to tighten or loosen unless some graphite grease is applied to the threads when the bolts are first put in place.

Angle fish-plates, Fig. 4, are intended to serve a two-

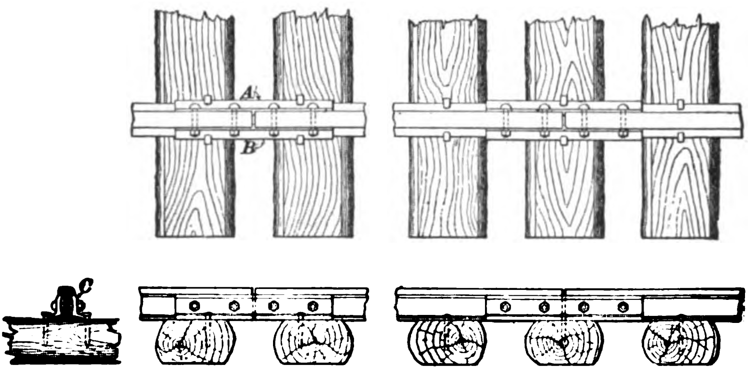


FIG. 4

fold purpose, namely, to join the rails and also, by their shape, to prevent the rail joint from sagging; this latter is accomplished to a certain extent, with long angle fish-plates, but it is better to have the tie come under the joint. Angle fish-plates will be found serviceable on main entries where heavy cars and locomotives are used, as they possess considerable advantage over strap plates.

23. Joining Different Rail Sections.—Where a rail of one section is joined to that of a smaller section, the fish-plates should be fitted to the rails as perfectly as possible in the shop and the bolt holes bored to correspond with the bolt holes in the rails. The fish-plates will appear as in *a*, Fig. 5. The tie under such a joint is dressed to permit the sections of rails that have different heights to rest solidly on their bases; or in some cases iron plates *b* are placed under the smaller rail to bring it to its proper level with the larger rail. Such joints are necessary where more than one size of rail is used in a mine and special attention should be given them in laying a track. To avoid making a new fish-plate, a large fish-plate is often cut down; and if the bolt holes in the rails fit but one fish-plate, bolts are put only in one rail. Such joints are makeshifts and of doubtful practical use, although they may assist in preventing the rails from spreading; this latter feature is, however, doubtful, if the spikes are loose or the tie bad.

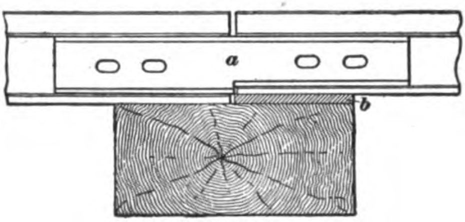


FIG. 5

24. Fish-Plate Bolts and Nuts.—Most fish-plate bolts are made with rounded heads, and to prevent their turning in the holes the necks are made oval in shape and should fit the slot in the plate, for if the bolts turn in the holes when screwing up the nut it is difficult to make a rigid joint or to loosen the bolt when necessary, with two men at work. If the holes are too large for the bolts, square-headed bolts may be used, but these are objectionable, as the wheel flanges may strike them. To free the fish-plates, the trackman is often compelled to cut the bolt, and while this may be the result of the bolt rusting it frequently is due to the bolt neck being too small for the fish-plate hole.

25. Railroad Spikes.—Light rails are usually fastened to the ties with $2\frac{1}{2}'' \times \frac{3}{8}''$ spikes, but a $3'' \times \frac{3}{8}''$ spike will give a more secure fastening. On account of the unevenness of cross-ties and the thickness of the rail base, which increases with the weight of the rail, the size of spikes should be such as to have a firm hold in the wood, and this is hardly possible of accomplishment with a spike less than 3 inches long under the head. The traffic also has a bearing on the size of spike used. On main entries with 40-pound rails, the spikes should be at least $3\frac{1}{2}$ inches by $\frac{7}{16}$ inch, and $4'' \times \frac{7}{16}''$ spikes

TABLE III

NUMBER OF RAILS, JOINTS, FISH-PLATES, BOLTS, AND NUTS PER MILE AND PER 100 YARDS OF TRACK

Length of Each Rail Feet	Number of Rails		Number of Joints		Number of Fish-Plates		Number of Bolts and Nuts Four of Each per Joint	
	Per Mile	Per 100 Yards	Per Mile	Per 100 Yards	Per Mile	Per 100 Yards	Per Mile	Per 100 Yards
18	586	33	586	33	1,172	66	2,344	132
20	528	30	528	30	1,056	60	2,112	120
22	480	27	480	27	960	54	1,920	108
24	440	25	440	25	880	50	1,760	100
26	406	23	406	23	812	46	1,624	92
28	377	21	377	21	754	42	1,508	84
30	352	20	352	20	704	40	1,408	80

TABLE IV

TRACK BOLTS

Weight of Rail in Pounds per Yard	Size of Bolts Inches	Size of Nuts Inches Square	Number Bolts in a Keg	For 30-Foot Rails	
				Number Kegs per Mile	Number of Yards of Track per Keg
12	$\frac{1}{2}\times 2$	1	793	1.8	991
14	$\frac{1}{2}\times 2$	1	793	1.8	991
16	$\frac{1}{2}\times 2$	1	793	1.8	991
18	$\frac{1}{2}\times 2\frac{1}{2}$	1	654	2.2	817
20	$\frac{1}{2}\times 2\frac{1}{2}$	1	654	2.2	817
25	$\frac{1}{2}\times 3\frac{1}{2}$	1	576	2.4	720
30	$\frac{5}{8}\times 3\frac{1}{2}$	$1\frac{1}{4}$	329	4.3	411
35	$\frac{5}{8}\times 3\frac{1}{2}$	$1\frac{1}{4}$	329	4.3	411
40	$\frac{3}{4}\times 3\frac{1}{2}$	$1\frac{1}{2}$	216	6.5	270
45	$\frac{3}{4}\times 3\frac{1}{2}$	$1\frac{1}{2}$	216	6.5	270
50	$\frac{3}{4}\times 3\frac{3}{4}$	$1\frac{1}{2}$	208	6.8	260
55	$\frac{3}{4}\times 3\frac{3}{4}$	$1\frac{1}{2}$	208	6.8	260
60	$\frac{3}{4}\times 4$	$1\frac{1}{2}$	200	7.0	250

are not uncommon. Usually four spikes are used to a tie on straight tracks, although on curved tracks this number may be increased to six. All the spikes should not be placed in the center of the tie, as the tie may split. If the spikes on the inside of the rail are placed on one side of the center and those on the outside on the other side of the center, the tie will not slide as it will if the spikes are placed opposite each other. Spikes are driven with a special hammer, known as a **spiking hammer**, or **maul**, Fig. 6. These vary in weight, but a 6-pound hammer with a long handle is heavy enough for mine work.

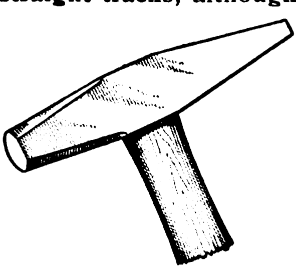


FIG. 6

TABLE V

RAILROAD SPIKES

Size of Spikes Under Head Inches	Number of Spikes per Keg of 200 Pounds	Ties 2 Feet Centers, Four Spikes per Tie			
		Weight of Spikes per Mile Pounds	Kegs per Mile	Weight of Spikes per 100 Yards Pounds	Number of Yards per Keg
$2\frac{1}{2} \times \frac{3}{8}$	1,342	1,575	7.87	90	223
$3 \times \frac{3}{8}$	1,240	1,703	8.51	97	207
$3\frac{1}{2} \times \frac{3}{8}$	1,190	1,775	8.87	101	198
$4 \times \frac{3}{8}$	1,000	2,112	10.56	120	166
$3\frac{1}{2} \times \frac{7}{16}$	900	2,346	11.73	132	150
$4 \times \frac{7}{16}$	720	2,933	14.66	167	120
$4\frac{1}{2} \times \frac{7}{16}$	680	3,106	15.53	177	113
$4 \times \frac{1}{2}$	600	3,520	17.60	200	100
$4\frac{1}{2} \times \frac{1}{2}$	530	3,985	19.92	227	88

26. Spiking Rails.—In laying track, two or more rails are joined with fish-plates and lined up with reference to the ends and centers of the ties and in as straight a line as possible. The rails are then spiked first at the joints, then at the center, then every other tie, and lastly each tie, this order of spiking being used so as to line the rail, which may be slightly bent during spiking. The second rail is put down in a similar manner and is properly spaced by the track-gauge. Spikes should be started vertically and after they have a firm hold in the wood a heavy blow will send them nearly home. The head is given a side blow toward the last in order to have it bend over the rail base. The tie must be held firmly against the base of the rail during the spiking; this is usually done by a man with a crowbar, cinch, or nipping bar, sometimes by two men with bars on each side of the tie. In laying mine tracks, it is not customary to have a large track gang. As one man holds the tie to the rail with the **cinch bar**, or **devil**, shown in Fig. 7, another

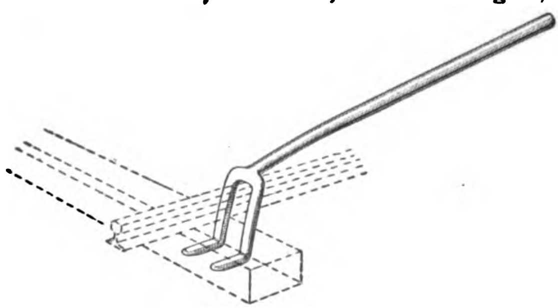


FIG. 7

drives the spikes. The cinch bar is a forked bar that straddles the rail and fits under the tie, and by putting weight on the handle the tie is brought close to the rail. One man sometimes uses this tool and drives the spikes at the same time.

27. Bending and Straightening Rails.—Mine rails are bent by the **rail bender**, or **jim crow**, Fig. 8, a tool that consists of a **U**-shaped iron with two hooks *a*, *b* at the ends, which pass over or under the rail. There is a feed-nut in the **U** bar at *c* to take a feed-screw *d*, the latter being turned by a nut and the wrench *f*. Rails should be bent gradually, the screw being given but a few turns, then loosened, and the bender moved a few inches farther along the rail and again tightened. This operation is repeated until the rail has reached the desired shape.

Sometimes rails are bent by nicking the base on one side with a cold chisel and then bending them by the aid of some

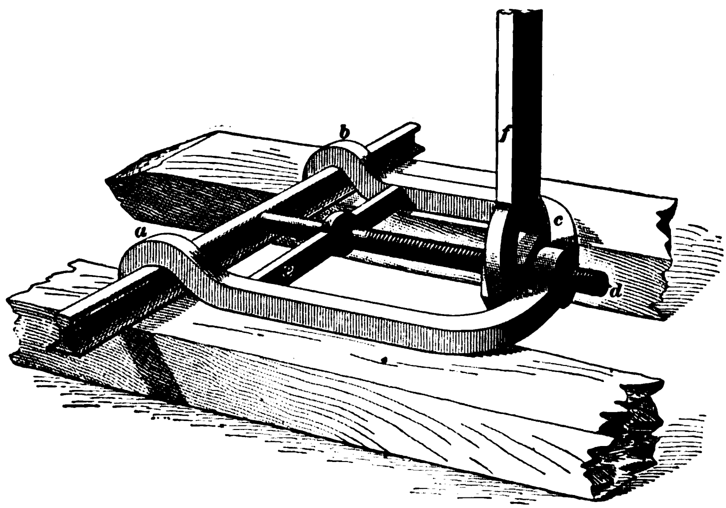


Fig. 8

stationary objects such as a prop and a coal pillar or over a pile of ties. The rails should be bent to the desired curve before being placed in the track, and this can best be accomplished in daylight outside the mine.

If rails are accidentally bent, they should be straightened before they are placed in the track. Kinks may be removed by jim crows, the straightening being done gradually, as when bending. Rails are not easily straightened by striking them with a sledge, but they can sometimes be straightened by bending them between the props and the ribs; in fact, at some mines this is the plan followed.

BALLASTING AND LINING THE TRACK

28. **Ballast** is the material filled in between and around the ties. The reason for ballasting a track is that the whole track may be firm and rigid. It is important that the ties should rest on firm ground, therefore the ballast is tamped under the ties, particularly under the ends of the ties near the rails. The weight of the cars comes on the rails and is transmitted through them to the ties. Where the ties are not properly tamped with ballast under the rails and ends, they move up and down as the loads pass over them and gradually this movement draws the rails out of line and causes the weight of the cars to shift to one side. This shifting of the weights makes the haulage difficult and also tends to throw the track still farther out of line.

29. The **choice of ballast** is generally confined to the material that is at hand; viz., draw slate. If the floor is hard, but inclined to be wet, broken sandstone topped with slate will form a ballast that will permit water to drain from the roadbed, and still keep the top dry. Where the floor is inclined to heave, it is removed from time to time and cinders substituted. Fireclay when wet allows the ties to sink, and it is then difficult for animals to travel over the roadbed; to correct this, the soft clay is dug out and removed and the hole is filled with cinders.

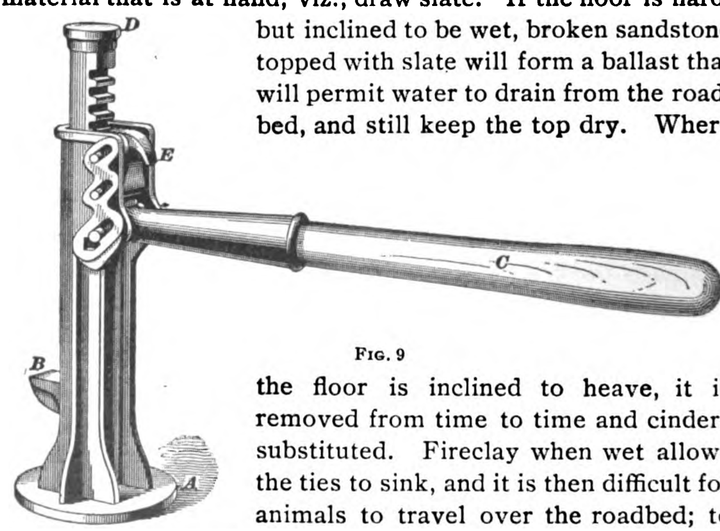


FIG. 9

30. The **tools** used for bringing the track up to grade are crowbars and track jacks, but the latter are preferable.

Fig. 9 shows a track jack resting on a base *A*. The jack is placed between the ties with the lug *B* under the rail. By means of the lever *C*, the rachet bar *D* is raised; and as *B* forms part of the bar, the track is raised at the same time. A tripper *E* is so arranged that the bar *D* can be dropped quickly and at will. When the track is raised to the desired grade, the ballast is shoveled under the tie until that rests firmly.

31. To **line up** the track, as soon as it has been raised to the proper grade, the track boss sights along the rails to see if they are in a straight line. If not, the track force by means of bars move the track and ties either right or left as the track boss directs until the alinement is perfect, sighting along the rail to a light held some distance away. In mines, it may be necessary to use a center stake or roof station with the track gauge, in order to line up the track, since the sight is not as good as in daylight and may not be trusted. It is often difficult, in mines, to find stakes with which to line tracks and to drive them in a hard bottom, for which reasons the centers given the entry drivers can be used by hanging plumb-lines to them.

A D-handled tamping shovel is used for tamping when the material to be tamped is fine; but for stone ballast, the tamping bar, Fig. 10, is preferred. The tracks having been

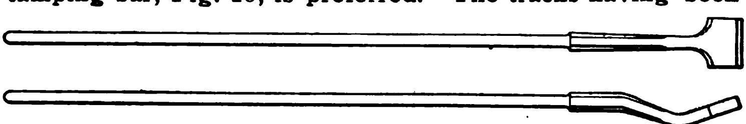


FIG. 10

lined, the tamping bar is used to pack the tamping under the tie, particularly under the ends where the weight comes.

CURVES ON MINE ROADS

32. Sharpness of Mine Curves.—When curves are necessary on haulage roads, they should be made with as large a radius as the conditions will allow, so as to permit of an easy movement of the cars. Mine curves must necessarily be much sharper than the curves used on the surface road, since cross-entries are usually turned at right angles from main entries and the rooms at right angles to the cross-entries. The curve in turning one entry off another should have a radius of from 60 to 100 feet for track gauges of from 36 to 48 inches, and where the wheel base of the cars is from 24 to 30 inches. Sharper curves are sometimes necessary, and, although not advisable, they are often used, particularly in connection with animal haulage.

33. Method of Designating Curves.—Curves may be designated, first, by the length of the radius to the center of the track; second, by the degree of the curve. The first of these methods is used for sharp curves and very generally in mine work, while the second applies particularly to surface work, although it is occasionally used when speaking of curves on mine roads.

34. Radius of Curvature.—The length of the radius is usually stated in feet, and for a railroad track is measured to the center of the track. To measure the radius of a curve, stretch a string or straightedge across a curve from *a* to *c*, as shown in Fig. 11, then measure the distance from the center of this string *b* and, at right angles to it, to the point *d* on the curve, the points *a*, *d* and *c* being all on the inner edge or gauge line of the rail head and then

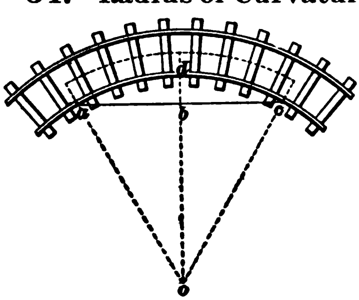


FIG. 11

$$R = \frac{\overline{ab}^2 + \overline{db}^2}{2db}$$

If ab and db are measured in feet, the radius will be given in feet; if measured in inches, the radius will be given in inches. If the measurements are taken on the inner rail of a curve, one-half the track gauge must be added to the calculated radius to give the radius of the track. If the measurements are taken on the outer rail of the curve, one-half the

TABLE VI

DEGREE AND RADIUS OF CURVATURE

Degree	Radius	Degree	Radius	Degree	Radius
1	5,729.65	35	166.28	68	89.42
2	2,864.93	36	161.80	69	88.28
3	1,910.08	37	157.58	70	87.17
4	1,432.69	38	153.58	71	86.10
5	1,146.28	39	149.79	72	85.06
6	955.37	40	146.19	73	84.06
7	819.02	41	142.77	74	83.08
8	716.78	42	139.52	75	82.13
9	637.28	43	136.43	76	81.21
10	573.69	44	133.47	77	80.32
11	521.67	45	130.66	78	79.45
12	478.34	46	127.97	79	78.61
13	441.68	47	125.39	80	77.79
14	410.28	48	122.93	81	76.99
15	383.07	49	120.57	82	76.21
16	359.27	50	118.31	83	75.46
17	338.27	51	116.14	84	74.72
18	319.62	52	114.06	85	74.01
19	302.94	53	112.06	86	73.33
20	287.94	54	110.13	87	72.64
21	274.37	55	108.28	88	71.98
22	262.04	56	106.50	89	71.34
23	250.79	57	104.79	90	70.71
24	240.49	58	103.14	91	70.10
25	231.01	59	101.54	92	69.51
26	222.27	60	100.00	93	68.93
27	214.18	61	98.52	94	68.37
28	206.68	62	97.08	95	67.82
29	199.70	63	95.69	96	67.28
30	193.19	64	94.35	97	66.76
31	187.10	65	93.06	98	66.25
32	181.40	66	91.80	99	65.75
33	176.05	67	90.59	100	65.27
34	171.02				

track gauge must be deducted from the calculated distance to determine the radius of the track.

Since the curves in mines are not always laid out with great accuracy, it is advisable to repeat the measurements at different parts of the curve; and in making the measurements these should not be taken from the ends of the curve, for if any portion of the straight track is included in the part measured the results will be incorrect.

EXAMPLE.—If the measurements are taken to the inside rail of a mine track whose gauge is 3 feet and the length of the cord ac, Fig. 11, is 24 feet, or 288 inches, and the vertical distance db is 12 inches, what is the radius of the curve measured to the center of the track?

SOLUTION.—Using the formula, $R = \frac{\overline{ab}^2 + \overline{db}^2}{2db}$, $ab = 288 \div 2 = 144$ in., and $db = 12$ in., then

$$R = \frac{144 \times 144 + 12 \times 12}{2 \times 12} = 870 \text{ in.} = 72 \text{ ft. } 6 \text{ in.}$$

One-half the gauge 3 ft. is 1 ft. 6 in., and adding this to 72 ft. 6 in., the radius of curvature to the center of the track, 72 ft. 6 in. + 1 ft. 6 in. = 74 ft. Ans.

The above method for determining the radius of curvature, although only approximate, is sufficiently accurate for most purposes.

Table VI for the relation between the degree of curvature and radius is calculated by the correct formula, as explained fully in *Mine Surveying*, Part 4.

35. Laying Out Curves.—Curves are sometimes laid out underground with the transit as in surface work, but there are a number of ways of doing this without the use of the transit that give very satisfactory results.

Suppose that it is required to connect the two headings A and B, Fig. 12, which are perpendicular to each other, with a curve of 60 feet radius. Prepare the device shown in Fig. 13, by taking three small wires or inelastic strings fg, gh, and gk, each 10 feet long; connect one end of each to a small ring and the other ends of two of them to the ends of a piece of wood $1\frac{2}{3}$ feet long; form a neat loop at the end f of the string gf. To use this device, lay off on the center line of the heading *B*, *cd* and *de* equal to 60 feet and 10 feet, respectively. Place the loop *f* of the device described over a small wire peg driven in at *e*, and the ring *g* over a similar peg at *d*. Take hold of the stick *hk*, pull the strings *gh* and *gk* taut, and place the center mark of *hk* on the center line of the heading *B*. Drive a small peg in at *m*, located by the point *k*, which is on the curve. Move the device

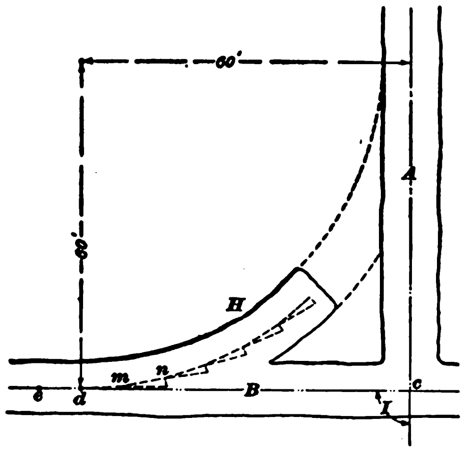


Fig. 12

Fig. 13

forwards, place the loop *f* over the peg at *d*, the ring *g* over the peg at *m*, and take hold of the stick *hk* and pull until the strings *gh* and *gk* are taut, and the strings *fg* and *gh* are in a straight line. The point *k* will fall on the curve at *n*, which mark by driving in a peg. To locate other points, proceed exactly as in the last step. The distance *cd* in any case is found by the formula,

$$cd = R \tan \tfrac{1}{2} I \qquad (1)$$

in which R = radius of curve;

I = intersection angle of center line of headings.

The length of the stick *hk* is found by the formula,

$$hk = \frac{100}{R} \qquad (2)$$

36. Fig. 14 shows a graphic method of laying out curves, when it is desired to connect a main entry *a* with a cross-entry *b* by a curve of a given radius. *c* is the point of curve on the main-entry center line and *d* is the point of tangency on the center line of the cross-entry, which is assumed to be turned off at right angles from the main entry. From *c* and *d* describe arcs with a radius equal to the desired radius of curvature, thus locating the center *e* of the curve. From this point with the same radius describe the

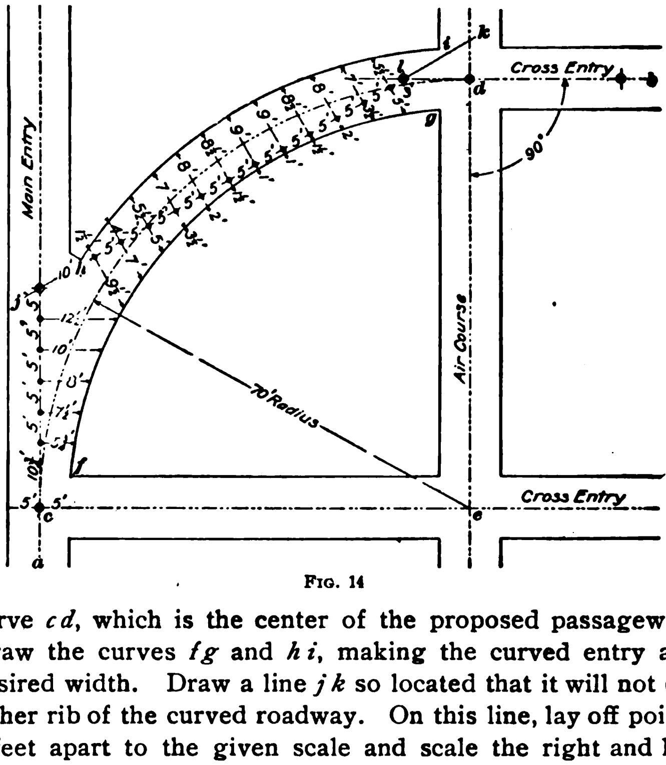


FIG. 14

curve *cd*, which is the center of the proposed passageway. Draw the curves *fg* and *hi*, making the curved entry any desired width. Draw a line *jk* so located that it will not cut either rib of the curved roadway. On this line, lay off points 5 feet apart to the given scale and scale the right and left distances to the rib, as shown in the figure. If a plat of this kind is drawn at a large enough scale, the angles and distances may be scaled sufficiently accurate for the practical work of the mine foreman. A blueprint or tracing of the plat is furnished to the mine foreman, and from it he lays off the right and left distances from the center line of the main entry and from the line *jk*. The line *jk* is located by means of two stations placed with the transit at *b* and a point either to the right or left of *b*, as may be most convenient, and along the line *b l*. For the distances given in the illustration and the radius of curvature of 70 feet, the angle *c j k* as taken from the drawing is about 120° 15′; the angle at *j l d*, about 149° 45′; the distance *c j*, 35 feet 9 inches; *j l*, 58 feet; and *l d*, 11 feet 6 inches. These distances are given as about so much to show that they are scaled from a drawing and are not calculated by trigonometry.

37. Difference in Length of Inner and Outer Rails of a Curve.—It is evident that the radius of the outer rail of a curve is greater than that of the inner rail, and with short mine curves this is more noticeable than in curves of larger radius. In determining the number of short rails for a curve, the following rule will give the difference in length of the inner and outer rails:

Rule.—*Multiply the gauge of the track by the length of the curve, all in feet, and divide the product by the radius of the curve.*

EXAMPLE.—A curve having a radius of 70 feet is 115 feet in length; the gauge of the track is 3.5 feet. What will be the difference in length between the inner and outer rails of the curve?

SOLUTION.—The difference in the lengths of the inner and outer rails, in this case, is, calling this difference x

$$x = \frac{3.5 \times 115}{70} = 5.75 \text{ ft. Ans.}$$

38. Middle Ordinate for Curving Rails.—When laying track on curves in order to have a smooth line, the rails must be bent to conform to the center line of the curve. As a guide in bending rails, the middle ordinate of any rail can be found from the following formula,

$$m = \frac{c^2}{8R}$$

in which m = middle ordinate;
c = chord, assumed to be of same length as rail;
R = radius of curve.

EXAMPLE 1.—What is the middle ordinate of a 30-foot rail, the radius of the curve being 70 feet?

SOLUTION.— $m = \dfrac{30^2}{8 \times 70} = 1.6$ ft. Ans.

EXAMPLE 2.—What is the middle ordinate for an 80° curve, the rail being 24 feet long?

SOLUTION.—The radius of an 80° curve is, by Table VI, 77.79 ft.

$$m = \frac{24^2}{8 \times 77.79} = \frac{576}{622.32} = .925+ \text{ ft. Ans.}$$

To insure a uniform curve to a rail, the quarter ordinates at b and b', Fig. 15, should be tested; and in all cases the quarter ordinates should be three-quarters of the middle

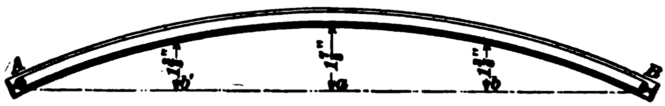


FIG. 15

ordinate. If the rail is properly curved, the quarter ordinates for an 8° curve, given in Fig. 15, will be $\frac{3}{4} \times 1\frac{7}{8} = 1\frac{13}{32}$, or practically $1\frac{3}{8}$ inches.

39. Widened Track Gauge on Curves.—Theoretically, in order that the trip may pass around the curve most easily, every axle in a train should point to the center of the curve, and the outer wheels should be larger than the inner. This is, of course, impracticable, since the axles must be fixed and the wheels of the same size. A slight difference in the diameter of wheels is secured by making the tread of each wheel inclined so that the diameter near the flange is greater than that on the outside of the tread.

With fixed axles and on a sharp curve, the running gear of a car or locomotive binds as the front wheel presses against the outside rail and the rear wheel against the inside rail. To overcome this, the difference in gauge between the car and the track is increased on curves. The amount of this increase depends on the gauge of the track, the wheel base of the car, and the radius of the curve, the maximum being limited, of course, by the tread of the wheels. Experiments have shown that, with a narrow-gauge track having sharp curves over which locomotives and cars with short wheel bases pass, a good rule is to widen the gauge of the track

$\frac{1}{16}$ inch for each $2\frac{1}{2}°$ of curvature, that is, on a 40° curve the track gauge should be increased 1 inch. On the very sharp curves frequently necessary in mines, the gauge should be widened as much as the wheel tread will allow, and in some cases it is well to lay guard-rails on the curves inside the rails, so that if one wheel mounts the track the other will not follow, but will pull it back on to the track.

40. Elevation of Outer Rail on a Curve.—When a trip of cars drawn by a locomotive or a mule goes around a curve, the centrifugal force crowds the outer wheel against the rails and tends to tip over the cars. This tendency depends on the speed of the train and the shortness of the curve, and to counteract it the outer rail of a curved track is raised so that the trip will lean inwards sufficiently to counteract the tendency to tip over at a given speed and on a given curve.

If the trip is hauled by a rope on sharp curves, the inner rail instead of the outer is elevated, since the pull of the rope tends to tip the cars inwards. In passing around a curve, the speed is usually slow and the tendency of the rope to tip the trip inwards is opposed to the tendency to tip outwards, due to centrifugal force. If these two forces balance each other, the two rails are laid at the same height. The degree of curve and the speed determine which, if either, of the rails shall be elevated. On a slope haulage, however, operated by a single rope, when the weight of the cars traveling on the slope is sufficient to draw the rope off the hoisting drum, the rails on curves should be elevated on the outside, as the centrifugal force only acts on the cars being lowered; the elevation in such a case should, however, be moderate, so as not to interfere with the trip when being drawn out by the rope, when, of course, the tendency is to tip the cars inwards. Table VII gives the elevation of rail for different degrees of curvature and for a 42-inch track, assuming a speed of 10 to 15 miles per hour.

It is not generally advisable to elevate the rail more than $4\frac{1}{2}$ inches, since it is not advisable to attempt to run trips around sharp curves at a high speed.

The rule for standard-gauge roads ($56\frac{1}{2}$ inches) on surface and for speeds of 25 to 35 miles per hour is to elevate the outer rail $\frac{1}{2}$ inch for each degree of curvature. An approximate rule often given for narrower gauges is to make the elevation proportional to the gauge based on the amount given above for standard gauge. Thus, for a 36-inch gauge, the elevation would be about two-thirds of the elevation for a $56\frac{1}{2}$-inch gauge of the same speed and curve.

The elevations of the outer rail given in Table VII correspond to the middle ordinates of the respective curves for a

TABLE VII

RAIL ELEVATION

Degree of Curve	Radius of Curve Feet	Elevation of Outer Rail Inch	Degree of Curve	Radius of Curve Feet	Elevation of Outer Rail Inches
1	5,729.6	$\frac{1}{8}$	10.0	573.7	$1\frac{1}{8}$
2	2,864.9	$\frac{1}{4}$	12.0	478.3	$1\frac{5}{16}$
3	1,910.1	$\frac{5}{16}$	15.0	383.1	$1\frac{5}{8}$
4	1,432.7	$\frac{7}{16}$	18.0	319.6	$1\frac{15}{16}$
5	1,146.3	$\frac{9}{16}$	20.0	287.9	$2\frac{3}{16}$
6	955.4	$\frac{11}{16}$	60.0	100.0	$4\frac{1}{2}$
7	819.0	$\frac{13}{16}$	112.9	60.0	$4\frac{1}{2}$
8	716.8	$\frac{7}{8}$	180.0	50.0	$4\frac{1}{2}$
9	637.3	1			

chord of 20 feet. Hence, a common rule to determine the amount of the elevation of the outer rail, for a speed of 15 miles per hour for a 3-foot gauge, is to measure the middle ordinate of a string 20 feet long, stretched as a chord on the gauge line of the outer rail. For higher or lower speeds, make the length of the string proportional to the speed; thus, for a speed of 12 miles per hour, use a 16-foot string, for 9 miles per hour, a 12-foot string, etc. Also the elevation should be proportional to the gauge; thus, for a 30-inch gauge, use five-sixths of the above elevation, etc.

The general rule is to begin to elevate the rail a short distance before the curve begins, this distance depending on the amount of elevation required. It is, however, not always practicable to do this in mine work.

41. Reduction of Grade on a Curve.—On surface railroads, it is customary to reduce the grade on a curve so that the resistance on the curve due to the grade and to the curve shall be equal to the resistance on the straight track at a steeper grade. A reduction of $\frac{2}{100}$-foot grade for each degree of curvature is often made on curves. For example, if a 20° curve occurs on a road that is being laid on a 5-per-cent. grade, the grade on the curve is reduced $20 \times \frac{2}{100} = \frac{40}{100} = .4$ per cent., thus giving a compensated grade of $5 - .4 = 4.6$ per cent. on the curve. This rule applies to light grades and curves of a large radius, but for heavy grades and sharp curves, such as it is sometimes necessary to use in mine work, the rate of compensation should be increased. On a narrow-gauge road, a compensation of $\frac{3}{100}$ foot for each 100 feet and for each degree of curvature is said to give good results on 40° curves and 4-per-cent. grades. It is not usually customary in underground work to thus reduce the grade on curves, as the gain will not ordinarily warrant the additional labor necessary to put in the work properly.

MINE SWITCHES

42. Definitions.—A **switch** is a device for enabling a car or a trip of cars to pass from one track to another. The term switch is also frequently used in a loose sense to apply to the whole side track or turnout, and a car standing on a side track is frequently said to be standing on the switch. The use of the term here, however, will be restricted to the first definition and will not include the side track or turnout. The several parts of a mine switch are shown in Fig. 16.

There are two general kinds of switches in use, the split switch shown in Fig. 17, and the stub switch, Fig. 24.

The **point of switch** is that point in the track where a car passes from the main line on to the rails of a turnout.

The **point of frog** is the intersection of the gauge lines of the main track and the turnout.

The **lead of a switch, or frog distance,** is the distance measured on the main line from the point of switch to the point of frog. Owing to the limited room for side tracks on mine-haulage roads, the lead of mine switches is often much shorter than is used on surface roads and generally consists of but a single length of rail. Where locomotives or rope

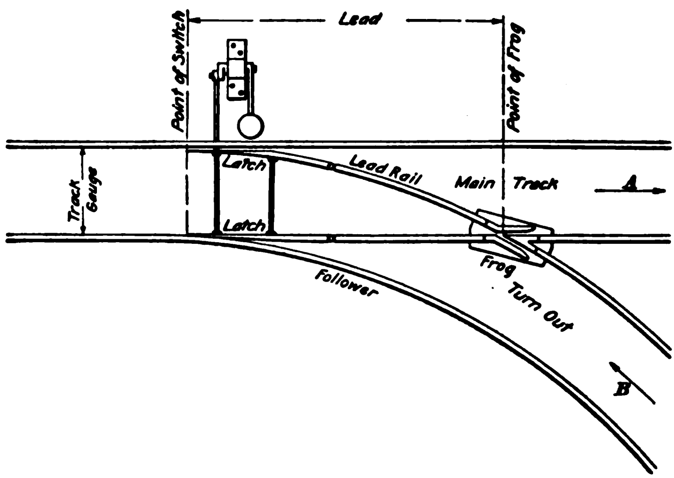


FIG. 16

haulage are used, the lead of the switches must be longer than where mule haulage is used and the switches must be much more carefully designed and laid out.

The **lead rail** of an ordinary mine switch is the turnout rail lying between the rails of the main track; the **follower rail** is the rail on the other side of the turnout corresponding to the lead rail, as shown in Fig. 16. The terms lead rail and follower rail are only used in reference to small mine switches.

Switch rails, switch points, or **latches** are the movable rails that open and close the switch. These rails are tapered from the heels of the rail *a'*, *b'*, Fig. 17, to the points *a*, *b* to allow them to fit tightly against the permanent rails when the two are thrown together so that the flange of the wheel will not catch the point of the switch rail. A switch is said to be *open* when it is arranged so that the cars pass from the

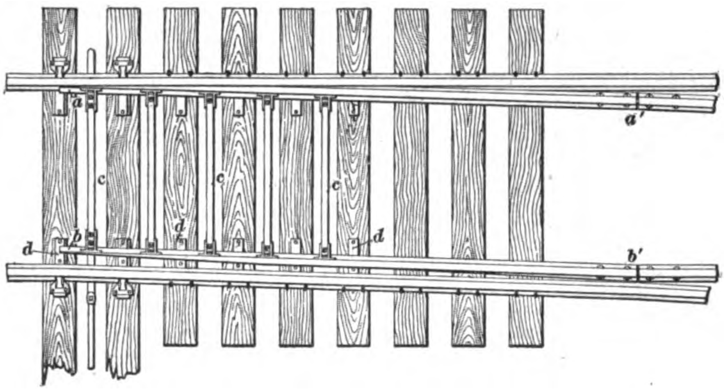


FIG. 17

main track to the side track, or from the side track to the main track; and *closed* when it is arranged so that the cars pass along the main track.

The **throw** of a switch is the distance through which it moves measured at the point.

43. Length of Switch.—Where locomotive or rope haulage is used, requiring a longer lead than for mule haulage, the switch rails may be of any length up to about 15 feet, depending on the lead of the switch. Long switch

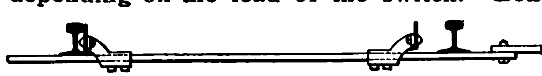


FIG. 18

points *a a′ b b′* are shown in Fig. 17, the points being joined by bridles or tie-rods *c*. A detail of the bridle is shown in Fig. 18.

The length of the switch points for an ordinary mine switch is generally only from 2 to 3 feet; these short rails are called latches. The latches turn on a pin *a*, Fig. 19, that holds them in position and which is usually a spike driven into a tie through a plate welded to the base of the latch rail at its heel, or broadest part. The bridle *b* joining these mine latches is usually a flat piece of iron passing under the rail and fastened to the latch, as shown. The latch may

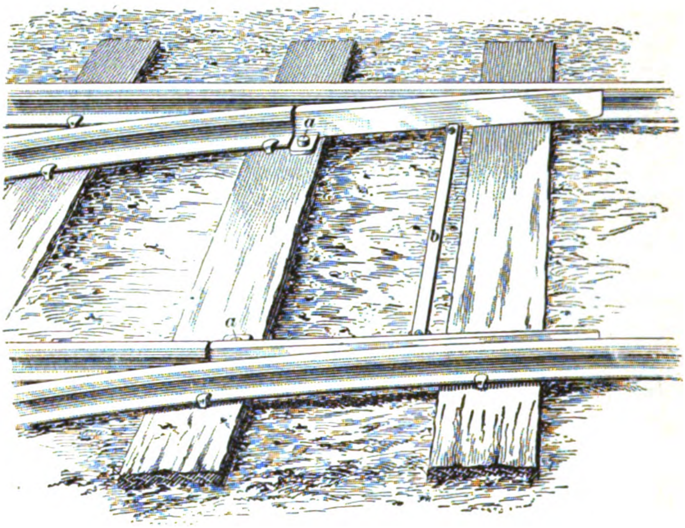


FIG. 19

be made of heavy bar iron, tapered to a point, with a bolt-hole through the heel of the latch.

The switches thus far described are known as **split switches,** a term applied to any form using switch points or latches.

FROGS

44. Definitions.—A **frog,** Fig. 20, is an arrangement

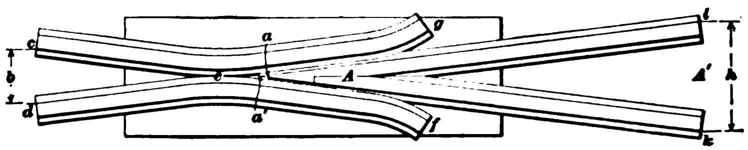


FIG. 20

of rails that permits the flanges of the car wheels to pass the point where two rails intersect. A frog is required in every switch at the point where the lead rail crosses the rail of the main track. The wedge-shaped part *A* is the **tongue,** and the extreme end *a* of the tongue *A* is the **point.** (The *point of frog* is very close to the point of intersection of the gauge lines of the two rails. If the frog point were ground to a knife edge, this point would correspond to the intersection, but since the frog point is blunt the intersection is a short distance ahead of the point.) The space *b* between the ends *c* and *d* of the rails is the **mouth,** and the channel that they form at the narrowest point *e* is the **throat.** The **heel** of the frog is that end lying from the point of the switch, that is, toward *A'*. The **toe** of the frog is the end lying toward the switch, that is, toward *b*. The width *h* of the frog is called its **spread.** The **frog angle** is the angle between the gauge lines meeting at *a'*. The **length** of the frog is the distance *d l* or *c k* between the toe and heel measured on either rail. The ends of the rails *f* and *g* are curved forming **wings,** which guide the car wheels over the frog.

45. Kinds of Frogs.—There are several kinds of frogs. That shown in Fig. 20 is made up by riveting sections of rail to a heavy iron plate. Fig. 21 shows a frog that is a solid iron casting with grooves or flangeways *a* for the

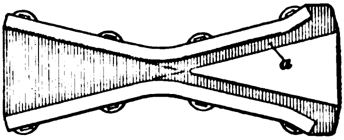


FIG. 21

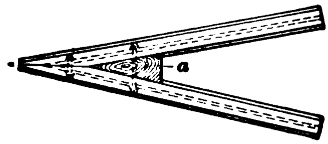


FIG. 22

wheel flange to travel in as it crosses the frog. An objection to the cast frog is that it works loose from the ties and requires constant attention; also, when the spikes once work loose, they will not again hold in the same holes.

Fig. 22 shows a form of frog frequently used in mines, made by bolting together two rail ends beveled so that they fit properly. A hard oak block *a* placed in the frog angle between the two rails helps to stiffen the frog.

The frog and the rails for a short distance on either side of it are frequently elevated so as to force the car wheels against the unbroken rail on the other side of the track when crossing the frog.

46. Frog Number.—The different sizes of frogs are designated by manufacturers by numbers, which are obtained by dividing the length *d l*, Fig. 20, by the sum of *b* and *h*. Thus, if the length *d l* is 5 feet; *b*, 5 inches; and *h*, 10 inches; the number of the frog will be $\frac{5 \times 12}{5 + 10} = 4$. Frog numbers run from 4 to 12, including half numbers, the spread of the frog increasing as the number decreases. If the frog angle is known, the frog number may be calculated by the formula,

$$N = \frac{1}{2 \sin \frac{1}{2} a}$$

in which N = frog number;
a = frog angle.

47. Frog Angle.—The angle *l a′ k*, Fig. 20, formed by the rails that form the tongue is termed the frog angle. In Fig. 23, the lines *a d* and *a c* form the tongue of the frog

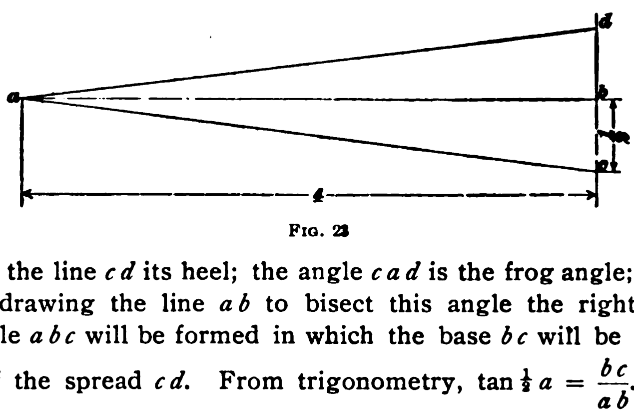


FIG. 23

and the line *c d* its heel; the angle *c a d* is the frog angle; and by drawing the line *a b* to bisect this angle the right triangle *a b c* will be formed in which the base *b c* will be one-half the spread *c d*. From trigonometry, $\tan \frac{1}{2} a = \frac{bc}{ab}$. If the length *a b* is 4 and the width *d c* is 1, *b c* will be $\frac{1}{2}$. Substituting these values, $\tan \frac{1}{2} a = \frac{\frac{1}{2}}{4} = \frac{1}{8} = .125$, or $\frac{1}{2} a = 7° \, 8'$, and $a = 14° \, 16'$.

STUB SWITCHES

48. **The stub switch** is often used in mines instead of the split switch, because it is cheaper and can be readily made in the blacksmith shop. The switch rails, *a*, *b*, Fig. 24, have

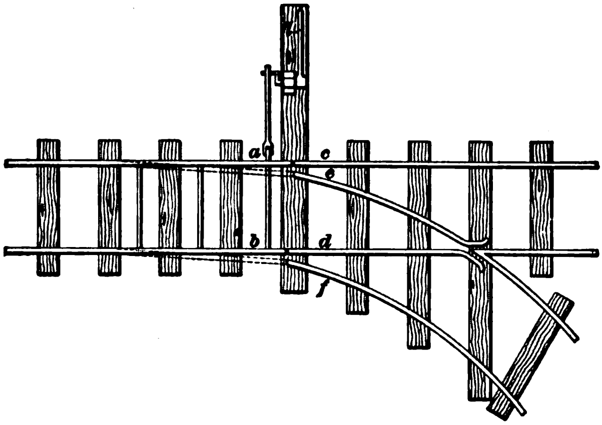


FIG. 24

stub ends and do not join the fixed rails *c*, *d*, *e*, *f* by about $\frac{1}{4}$ inch. The rails *a* and *b* are connected by a bridle and can be moved by a lever *l* so that the ends come opposite to the rails *c* and *d* or *e* and *f* and thus make a practically continuous track. The ties underneath the rail ends must be wide and solid, and underneath the rails a plate is needed to prevent the metal from cutting into the ties and at the same time to permit of their being readily shifted. The lead of a stub switch is shorter by the length of the switch rail than the lead of a split switch.

OPERATING SWITCHES

49. **Switch Levers.**—The small latches are frequently moved into position by the hand or foot without the use of a lever, but the longer switch points require a lever to move them.

A simple form of bell-crank lever commonly used in mine switches is shown in Fig. 25. The ends of the bridles *a* connecting the two loose rails of the switch are joined to the switch rods *b*, which are pivoted at *c* to the end of the bell-cranks *d*, which are rigidly attached to the rod *e* supported

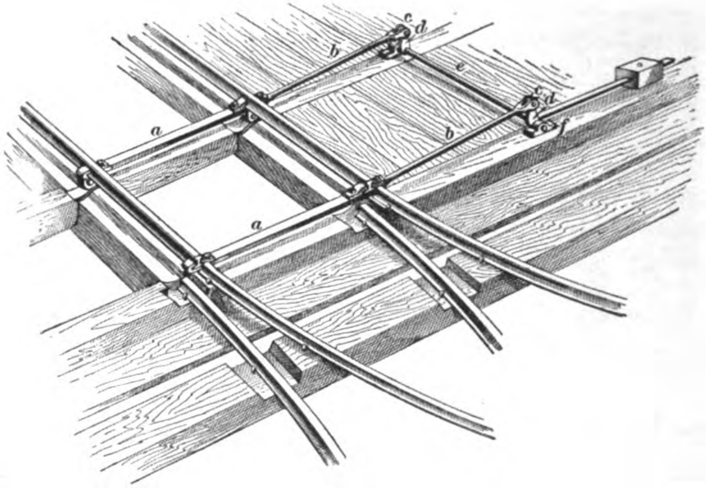


FIG. 25

in the pedestals *f*. By throwing the lever into the opposite position from that shown, the stub switch is thrown to the other rails.

50. A different form of lever has been illustrated in Fig. 24. The crank on the switch lever must be of such a length that when the lever is thrown the movable rails will line up with the fixed rails. In making the crank, care should be taken to center the pins so that the throw will not be too long or too short, otherwise the bridles will be bent or the cars may be derailed. The length of the crank should be one-half the length of the throw; in other words, the distance the rails must be moved will be twice as long as the crank from center of shaft to center of pin.

51. A simple form of switch stand is shown in Fig. 26. The end of the bridle is connected by the switch rod *a* to the end of the lever *b*. This lever is pivoted at *c*, and by moving the arm *b* backwards and forwards the bridle and switch are moved in a direction opposite to that in which the lever is moved. The lever is kept in place by a pin, put through holes in the stand, and the whole stand is spiked to the tie *d*.

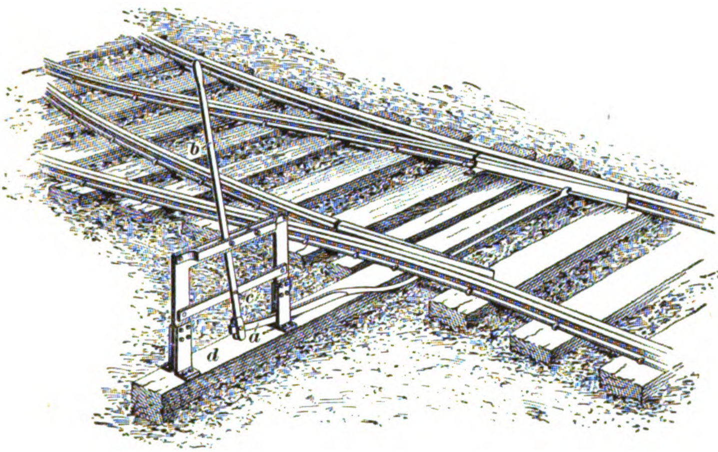


FIG. 26

52. A target switch stand, Fig. 27, similar to those used on the surface is sometimes used in the mine in connection with motor haulage systems, and particularly at important points on the haulage road. The target used on the surface is replaced underground by a lantern *a*.

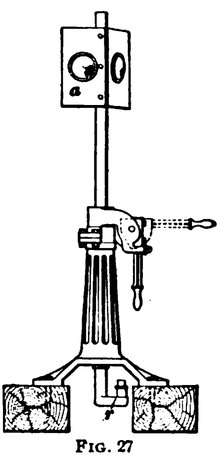


FIG. 27

53. An **automatic switch** is one in which the latches are always set in one position, being moved by a spring pole, a coiled spring, or balance weight that allows the latch to open sufficiently for a car to pass and then causes it to return to its original position. Automatic switches are used where the cars always pass over a switch in the same direction. In mine work, a hickory spring pole is generally used to return the switch to its place; a strong pole 8 or 10 feet long is spiked to the ties outside of the rail, or on one side of the track, and run through a loop attached to the track.

54. A **switch-rod** or **head-rod** is the heavy rod connecting the ends of the bridle with the crank-arm *r*, under the switch stand shown in Fig. 27, or the rod *b*, Fig. 25. The switch rails slide on iron plates *d* spiked to the ties, as shown in Fig. 17.

ROOM SWITCHES

55. As the cars are usually hauled into and out of the rooms by mules or pushed by hand, the **room switches** do not need to be as elaborate as those on the main roads. Fig. 28 shows a room switch with a cast-iron frog *f* and fixed points *a* and *b*.

The advantages of this switch are fixed points and the time saved when bringing cars from the rooms. Unless the point *a* is in line with the main track, the point *b* is liable to derail the car or cause it to run into the switch. This, however, can usually be avoided by making the rail *c* somewhat lower than the rail *a*, thus causing the car while passing to cling to the rail *c*, and readily pass between the point *b* and the rail *c*, and at the same time causing the wheel on the opposite side to take the rail *a*. Another great trouble experienced with this kind of a switch is that where the wheels are allowed to remain on the cars after grooves have been worn in their treads, the wheel will invariably follow the rail *d*. The point *b* should be higher than the rail *c*, so that the tread of the wheel will not strike the rail *c* while the car is leaving the switch. The rail *c* being lower than the rail *a*, it is obvious that when a car is to be taken into the switch, the driver will have to push the car toward the rail *d*, so that the wheel will take the rail *b* and the flange of the wheel on the opposite side will pass between the point *a* and the rail *d*.

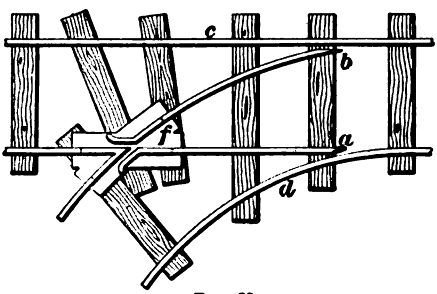


Fig. 28

This form of switch is not applicable in the case of mechanical haulage, because it does not give an unbroken main line, which is essential to the steady movement of the trip.

56. The switch shown in Fig. 29 has loose latches *b*. Instead of a frog, a frog latch *c* is used, which requires the lead rail *a* to be raised a certain height above the rail of the main track, so that the latch *c* can be thrown across this rail. The latch *c* is held in position at one end by a strong bolt, and at the other end by a piece of iron spiked to a plank underlying the frog, as shown. By the use of this switch, the main track is broken only at the point of switch.

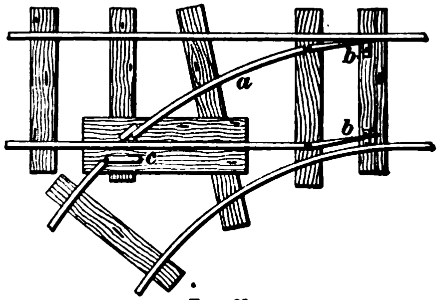


Fig. 29

57. Fig. 30 shows a form of switch giving an unbroken main track. The lead rail of this switch has a fixed point; a frog latch *c* is used similar to that shown in Fig. 29, and a switch latch *a* is used on the follower rail. This latch has a slight projection on its under side to prevent its slipping off the rail of the main track when in use. This form of latch is undesirable, since, if, by the negligence of the driver the latch is not removed after being used, it will derail cars on the main road, since it is not easily pushed aside by a car passing out.

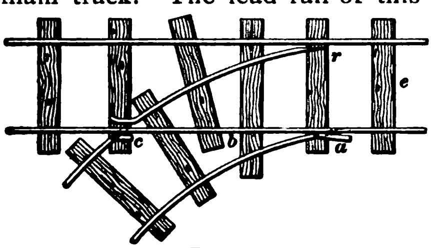


Fig. 30

58. Special Switches.—Fig. 31 shows a rough arrangement where a turnout or any other condition requires the temporary use of a switch. The ordinary form for narrow gauges consists of a movable rail *a*, about 6 feet long, pivoted on a center *b*. Where the curve is not great, this arrangement acts admirably where cars are pushed by hand, but for mule

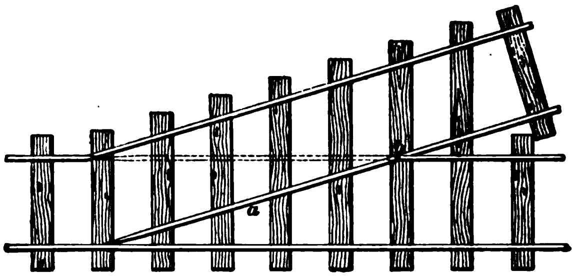


FIG. 31

or locomotive haulage it is not recommended. The dotted line shows the position of the rail *a* when the straight road is in use.

59. Fig. 32 shows a switch for permanent tracks in coal mines. No frog or latch is required. By turning the lever *h*, the throw rod *o* moves the cranks *i k m*, so that the rails *r* will face the rail *d f*, the rail *n* will face the rail *b*, and the rail *g* will face the rail *f*. The lead and other rails can be reduced to any required length to suit circumstances. When the lead rail *f d* is from 12 to 16 feet long, and the other lengths are

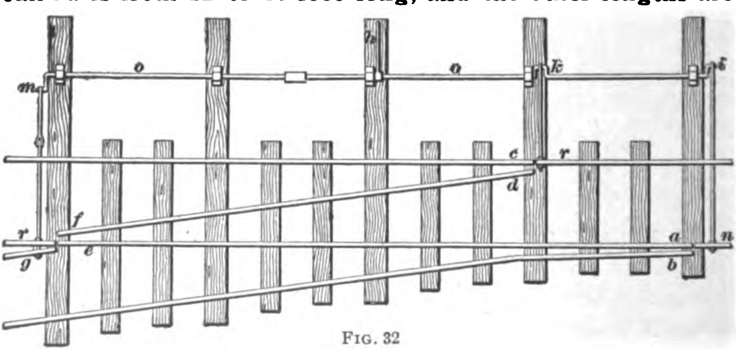


FIG. 32

in proportion, the switch gives excellent results. It should not be made of less than 20-pound rail, and heavier will be better. The objection to this switch is that the point of curve comes where the stub ends of the rails face each other and there is an angle formed that causes the car to lurch.

60. Fig. 33 shows a double switch sometimes used where two turnouts enter the main road at the same point. The short curves or "kinks" in the rails at the points *a* and *d* are objectionable, as they are apt to derail the cars if they are

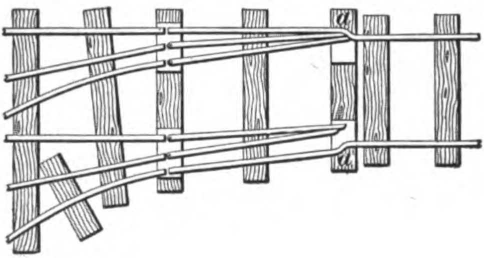


FIG. 33

running at a high speed. The switch is not in general use and it is preferable to use two switches, one set slightly ahead of the other.

61. Guard-Rails.—A **guard-rail** is a short length of rail spiked to the ties on the inside of the track opposite a frog. There is between the guard-rail and the main rail just sufficient space for the flanges of the car wheels to pass readily. The chief purpose of the guard-rail is to crowd the wheels against the unbroken rail and thus prevent their riding the point of the frog. There are two common forms of guard-rails. The form *A*, Fig. 34, is curved throughout its entire length, its central point *a* being set opposite the frog point, thus bringing the wheels to gauge at this point. This form of guard-rail is adapted to high speeds. The form shown at *B*, Fig. 34, is a straight guard-rail having its ends only slightly curved, so as to throw the flanges of the wheels against the unbroken rail; this is the common form used in mine work. Where there is much traffic on the haulage road,

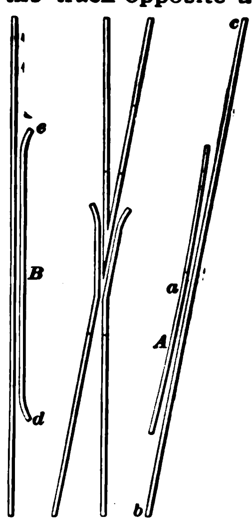


FIG. 34

guard-rails should be placed opposite each room frog to avoid derailment. If the guard-rails are not properly fastened, they will soon work loose, for which reason they are sometimes braced by wooden chairs being spiked to the ties. Guard-rails are seldom used on room switches, as there is not much danger of a car jumping the track at this point.

62. Grade Crossings.—Two types of grade crossings are commonly used in mines, as illustrated in Figs. 35 and 36. In Fig. 35, both the main line and the cross-road are on the same level, and the crossing is made by the ordinary form of crossing frog, consisting of rail sections spiked in place as shown. This form of frog differs from a switch frog only in the frog angle. The inner square rail section forms the guard-rails for both tracks, and short wings, or outside guard-rails, complete the crossing.

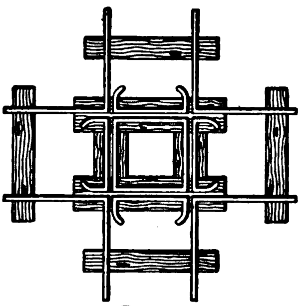


Fig. 35

63. In Fig. 36, the rails of the main haulage road are left unbroken, and the cross-road is slightly elevated, so that the bottoms of its rails are on a level with the top of the rails of the main road. Short cross-latches *c, c* are then used to complete the track of the cross-roads. The cross-latches should each be held in place by iron plates placed at the end of the short rails *a* and having a shallow groove in which the end of the cross-latch may lie when in position. By this arrangement, the latch is more easily thrown aside by cars passing on the main track if through neglect they have been left in place.

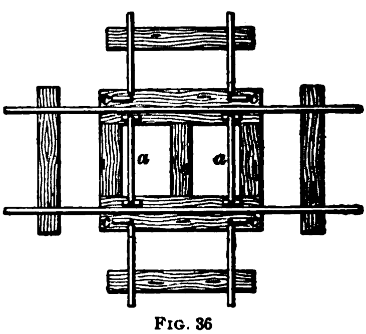


Fig. 36

LAYING SWITCHES

64. The kind of switch, length of lead, style of frog, etc., the necessary calculations, and the method of laying a mine switch will be determined by the conditions existing in the mine. In mine haulage, track room is limited; and to avoid unnecessary expense, it is generally necessary to locate either the point of frog or the point of switch, and lay the entire switch with respect to the location of this point. If the greatest possible length of side-track room is desired, the frog must be located on the main rail as far back in the entry as will afford the proper clearance for the side track at the point where the entry narrows. The point of switch is then located by measuring the proper lead from this point. In some cases, it will be necessary to locate the point of switch first, and the point of frog is then located by measuring the required lead from this point.

65. Calculation of a Switch.—Let AB, Fig. 37, be the main track, and hf the lead rail of the track turned off at one side. Using a split switch, qh is the switch rail, q its point and h its heel, f is the point of frog, the angle kfl equal to the angle qof, is the frog angle, fl being tangent to the lead rail at f, and pf measured on the straight rail is the lead of the switch.

In any given case, the track gauge pq is fixed.

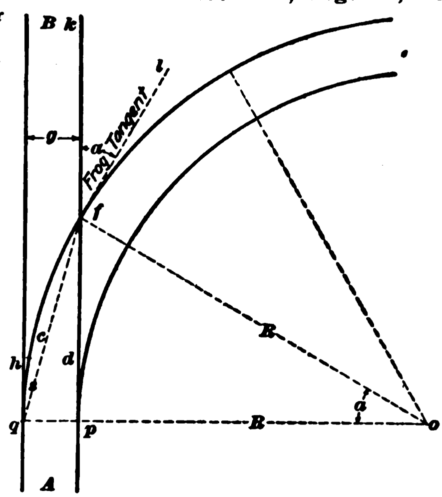


FIG. 37

The required factors are as follows: Radius (R), frog angle (a), frog number (n), frog distance or lead measured on the straight rail (d), chord (c) of lead rail reaching from point

TABLE VIII

Required Quantities	Known Factors					In Terms of Any Two Factors
	g and R	g and a	g and n	g and d	g and c	
R		$\frac{g}{1-\cos a}$	$2n^2 g$	$\frac{g^2+d^2}{2g}$	$\frac{c^2}{2g}$	nc
$\sin \frac{1}{2} a$	$\sqrt{\frac{g}{2R}}$		$\frac{1}{2n}$	$\frac{g}{\sqrt{g^2+d^2}}$	$\frac{g}{c}$	$\frac{c}{2R}$
n	$\sqrt{\frac{R}{2g}}$	$\frac{1}{2\sin \frac{1}{2} a}$		$\frac{1}{2}\sqrt{\left(\frac{d}{g}\right)^2+1}$	$\frac{c}{2g}$	$\frac{R}{c}$
d	$\sqrt{g(2R-g)}$	$\frac{g}{\tan \frac{1}{2} a}$	$g\sqrt{4n^2-1}$		$\sqrt{c^2-g^2}$	$R \sin a$
c	$\sqrt{2gR}$	$\frac{g}{\sin \frac{1}{2} a}$	$2ng$	$\sqrt{g^2+d^2}$		$\frac{R}{n}$

of switch to point of frog. Table VIII gives the simple formulas expressing the values of each of the required elements in terms of the track gauge (g) and one other element, together with a few formulas expressing these values in terms of any two elements.

66. The *length of the lead rail* from the point of switch to the point of frog is found in any case by the formula,

$$l = \frac{a}{180} \pi R \qquad (1)$$

The *length of a switch rail* s, depends on the throw t of the switch in inches, and the frog distance or lead d, and the track gauge g, both in feet, and is found by the formula,

$$s = d\sqrt{\frac{t}{12\,g}} \qquad (2)$$

67. Table IX gives the values of the several parts of a switch for frog numbers from 1 to 12 inclusive, for a track gauge of 3 feet. It will be observed that the lead of a stub switch is found by subtracting the length of the switch rail from the lead of a split switch, since in a stub switch the point of switch is moved toward the point of frog, a distance equal to the length of the switch rail, and the toe of the switch rail in this case is where the heel was formerly. All the dimensions are in feet, except the throw of the switch (t), which is in inches.

68. Laying a Crossover Switch.—Fig. 38 shows a

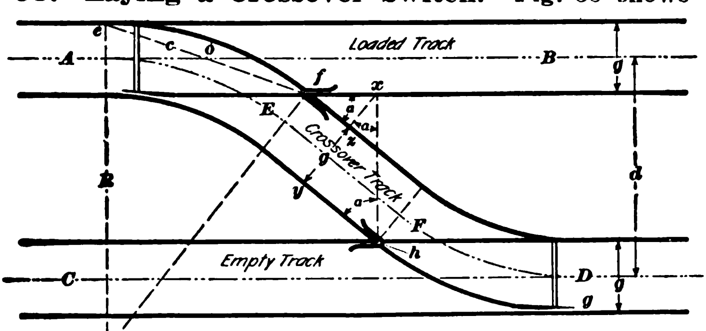


FIG. 38

crossover between the loaded track AB and the empty

TABLE IX

VALUES OF PARTS OF SWITCH FOR DIFFERENT FROG NUMBERS FOR TRACK GAUGE OF 8 FEET

Frog Number	Chord	Frog Angle	Lead Rail		Length of Switch Rail	Lead, or Frog Distance	
			Radius	Length		Split Switch	Stub Switch
n	c	a	R	l	s	d	$d-s$
1	6	60° 00′	6	6.3	2.0	5.2	3.2
2	12	28° 58′	24	12.2	4.0	11.6	7.6
3	18	19° 11′	54	18.1	6.0	17.8	11.8
4	24	14° 22′	96	24.1	8.0	23.8	15.8
5	30	11° 29′	150	30.0	10.0	29.8	19.8
6	36	9° 34′	216	36.0	12.0	35.8	23.8
7	42	8° 12′	294	42.0	14.0	41.8	27.8
8	48	7° 10′	384	48.0	16.0	47.8	31.8
9	54	6° 22′	486	54.0	18.0	53.8	35.8
10	60	5° 44′	600	60.0	20.0	59.8	39.8
11	66	5° 12′	726	66.0	22.0	65.8	43.8
12	72	4° 47′	864	72.0	24.0	71.8	47.8

track CD on a shaft bottom, or a parting or turnout in a mine. The crossover may consist of two turnout curves AE and DF, which are usually, though not necessarily, of the same degree of curvature. Assume, as is usual in mine practice, that the turnout curves terminate at the points of frog between which the track EF is a tangent. It is important to locate the frogs in the two main tracks, at such a distance apart that the cross-over rails will be tangent to the turnout curves. To do this, it is necessary to calculate the distance that one frog is ahead of the other, which is the distance fx measured on the main track. This distance is expressed by the formula:

$$fx = \frac{xz}{\sin a} = \frac{(d-g)\cos a - g}{\sin a} \qquad (1)$$

for $$xy = (d-g)\cos a, \text{ and } xz = xy - g$$

EXAMPLE.—If the mine tracks have a gauge of 3 feet and are laid 7 feet between centers, calculate the dimensions necessary to lay out a cross-over switch between the tracks, using a No. 4 frog.

SOLUTION.—First calculate the frog angle as follows: $\sin\frac{1}{2}a = \frac{1}{2n} = \frac{1}{2\times 4} = .125$; and $a = 2\,(7°\ 11') = 14°\ 22'$, and $\sin a = .248$; $\cos a = .968$. Then, substituting these and the given values in formula **1**,

$$fx = \frac{(7-3)\ .968 - 3}{.248} = \frac{.872}{.248} = 3.51+ \text{ ft. Ans.}$$

The length of the chord c of the lead rail is found by the formula,

$$c = 2ng = 2\times 4\times 3 = 24 \text{ ft. Ans.}$$

Fig. 38 is not platted to scale, nor for the dimensions given in this problem. The radius R of the lead-rail curve is found by the formula,

$$R = 2n^2g = 2\times 4^2\times 3 = 96 \text{ ft. Ans.}$$

The middle ordinate o for any length of chord c is given approximately by the formula,

$$o = \frac{c^2}{8R} = \frac{24^2}{8\times 96} = .75 \text{ ft., or 9 in. Ans.}$$

For half the length of chord, the middle ordinate is $\frac{1}{4}$ as great, or $2\frac{1}{4}$ in. Ans.

In locating crossover switches, regard should be had to the direction in which the cars move. The follower rail of a switch, opposite the point of frog, should be, say, $\frac{1}{2}$ inch for each foot of gauge lower than the main track at the frog point. The same is true for the unbroken rail of the main track opposite the frog. This will assist the cars on either track to clear the frog readily.

69. Laying a Turnout Switch.—The laying of a turnout switch differs from the work of laying a crossover switch only in the fact that the two curves join at a common point and form a single reverse curve, as shown in Fig. 39. The following method of laying out a turnout switch is often used by trackmen, as it avoids the use of numerical calculations. In Fig. 39, *a b* represents the straight track and *d c e* the tongue of the frog. Line the straight leg of the frog with the line *f g* of the main track and then stretch the string *i c h* so that it is tangent to the other leg of the frog. If a stub switch is to be used, the point of the switch will be between *j* and *i*. The point *j* is the point of curve and the distance *i c* should equal *i j*; if it does not, move the point of frog *c* until these distances are equal, then *c* will be in its proper place. Place two stakes at *l* and *m* so that *o l* = *g m* = the required distance apart of the tracks; next stretch pieces of twine *l m* and *c h* and find the point of intersection *n*; then measure *c n* and make *n p* equal to it, and then *p* will be the end of the reverse curve *j p* of the turnout. The middle ordinate of the curve *j c* is one-half of *i k* and the middle ordinate of the curve *c p* is one-half of *n r*.

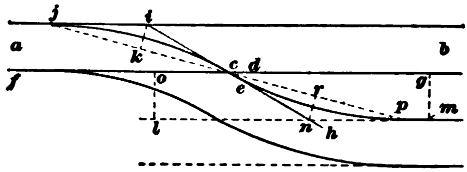


FIG. 39

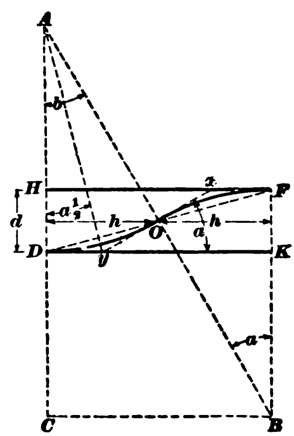


FIG. 40

70. Another method of laying out a turnout switch is shown in Fig. 40, where *D* represents the point of switch in one rail of the main track; O, the point of reverse curve; and F, the tangent point in the corresponding rail of the turnout. Drawing the radii AD and BF through the point of switch D and the point of tangency F, respectively, and joining the centers A and B by the line AB, the angle DAO is equal to the angle FBO. Calling this angle b and the distance between track centers d, we have

$$\cos b = \frac{2R - d}{2R} \qquad (1)$$

In this calculation, it is first necessary to find the radius R to be used with the given frog number n and the gauge g. Then, substituting this in formula (**1**), the angle b of curvature is found, or the angle subtended by the chords DO or OF. The total length of the switch DK, equal to $2h$, measured on the rail of the main track is then

$$2h = 2R \sin b \qquad (2)$$

The total length l of the rail from the point of switch in the main track to the point of tangency in the turnout is found by the formula,

$$l = \frac{b}{90}\pi R \qquad (3)$$

Example.—Find the length of a turnout switch measured on the main track, from the point of switch to a point opposite the switch in the turnout, when the distance between track centers is 8 feet, the track gauge 3 feet, and using a No. 4 frog.

Solution.—For the radius of curvature in this case, we have $R = 2n^2g = 2 \times 4^2 \times 3 = 96$ ft. Substituting this value in formula **1**, the angle of curvature is $\cos b = \frac{2R - d}{2R} = \frac{2 \times 96 - 8}{2 \times 96} = .9583$; and $b = 16° 36'$. Then, $2h = 2(96 \sin 16° 36') = 2(96 \times .2857) = 54.85$ ft. Finally, for the length of rail from point of switch to point of tangency we have,

$$l = \frac{16° 36'}{90°} \times 3.1416 \times 96 = \frac{16.6}{90} \times 301.59 = 55.62 + \text{ ft.} \quad \text{Ans.}$$

71. Laying a Room or Side-Entry Switch.—Assuming that the proper size of switch rails or latches and frogs, ties, and all material are where they are to be used, and having cleared the roadbed for the switch and the space between the ties of the main road, the first step is to determine the position of the frog on the main track. The frog is placed temporarily over the rail *tc*, Fig. 41, of the main track, in its approximate position. Keeping its straight wing in line with this rail, the frog is slid forwards or back on the rail until the track gauge held in position against the cross-wing *pf* of the frog shows the proper clearance at the corner *C* at the mouth of the room or side entry. After

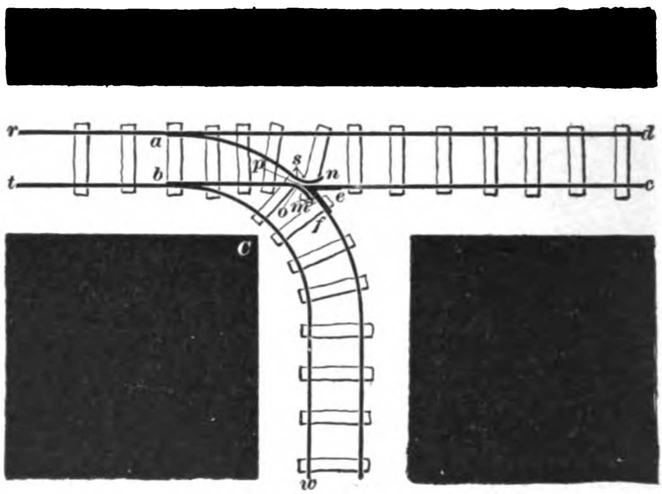


Fig. 41

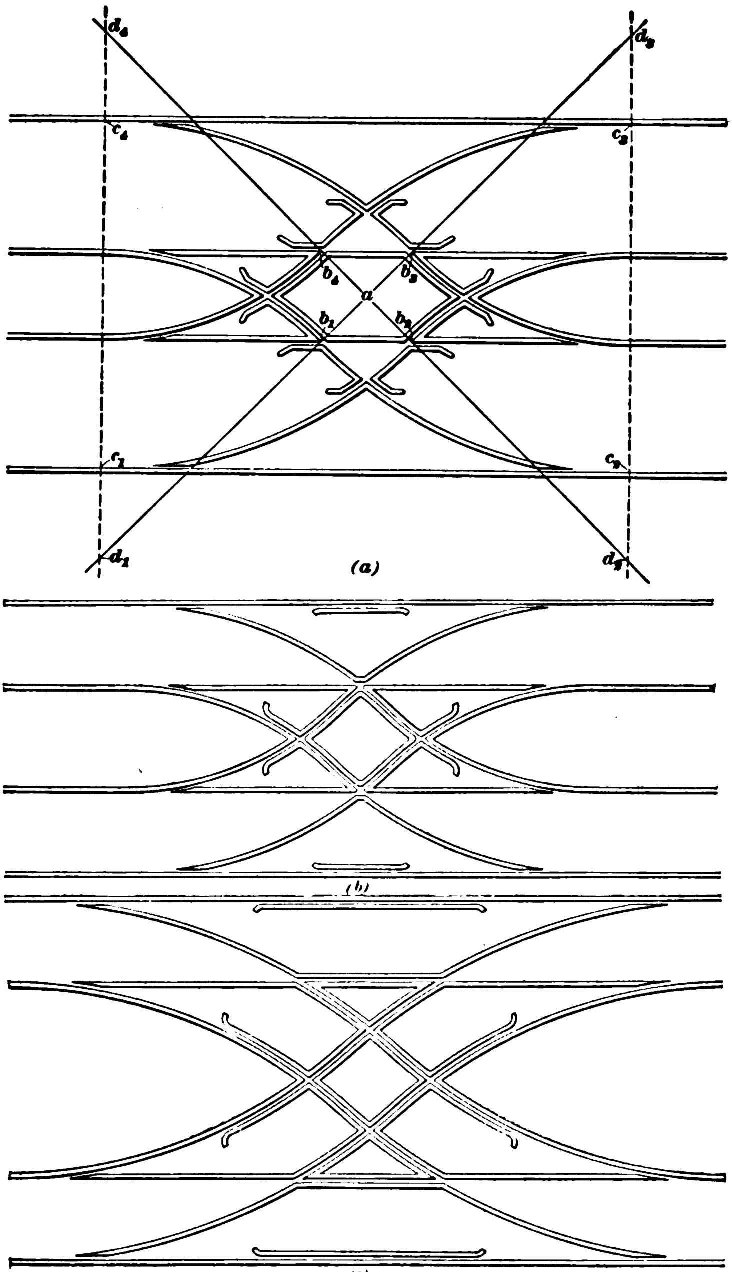
marking on the main rail *tc* the exact position of the frog, it is laid to the side of the track. A good wide tie is now selected and slipped into position under the main track at this point. It is generally possible to avoid cutting the main rail *tc* in more than one place. With this end in view, the straight switch rail *bom* is now laid in position over the main rail *tc*, and the point of switch *b* is marked on the main rail. From this point, the distance is measured on the main rail toward *t* to the next rail joint. A long rail is now selected for the follower rail of the turnout, and bent to the proper radius after laying off the measured distance for the straight portion at the proper end of the rail. This end of the rail remains straight, the balance of the rail being curved. Measurement is then made from the point *e* marked by the heel of the frog to the next rail joint in the main rail *tc* and a short length of rail selected for this place. If this length is only a few feet, it may be possible to find a long rail that will take the place of this short length and the next rail. Whenever moving the frog a few inches backwards or forwards will save cutting the rails, this should be done. The lead switch rail is now laid temporarily in position, and the switch point *a* marked on the main rail *rd*.

The switch bed is now prepared by slipping into position under the rails of the main track proper switch ties. These can generally be placed between the ties already in position, some of which may, however, have to be removed or shifted in their position to make room for the new ties. In some cases, all the main-track ties are replaced by long switch ties extending under both tracks, but this is not the usual practice in laying a room switch. The main rail *rd* that is to remain unbroken should now be spiked to the switch ties. If a stub switch is to be used, proper provision must be made in this regard for the point of switch. The main track should remain unbroken, and the traffic should not be interrupted while laying the switch ties. Everything is now ready for breaking the main rail *tc*. This is done by first breaking the joint inby from the point of frog. When this rail is removed, the short length of rail and the frog are placed in position. In like manner, the switch rail is next put in, having removed the main rails to make room for this and for the follower rail of the switch. The frog is now lined with the main rail *tc* and spiked to the switch ties, the short length of rail being, at the same time, spiked and bolted to the track rail and to the heel of the frog. The follower rail of the switch is next lined with the main rail *tc* and spiked to the ties near the point of switch, and coupled to the main rail at this end. The curved portion of the follower rail is then spiked to the switch ties, using the track gauge to obtain its proper position opposite the point of frog. An allowance of about $\frac{1}{2}$ inch should always be made in the width of the track at the point of frog to give ample clearance. When the follower rail is thus laid in place, the straight switch rail *bom* is spiked in position in the main track. If latches are used, these are temporarily spiked so that the traffic may be resumed on the main rail.

Having lined up the main rail tc across the switch, the lead rail of the switch is laid in place and spiked to the switch ties, using the track gauge to obtain the proper distance from the follower rail already in position. The work of laying the rails of the side track is then completed by laying the balance of the rails beyond the frog and extending them into the chamber. Where a switch stand is used, this is now placed in position and spiked to the switch tie at the point of switch. When everything is in position, the tracks are leveled and the switch ties firmly tamped. An important point in the laying of any switch is to elevate the frog slightly above the opposite rails of the main track and the turnout. The purpose of this is to throw the car against the opposite rail when crossing the frog, so that any loose wheels will not catch the point of frog in passing. The follower rail of a switch leading to the dip, however, may be raised level with the frog.

72. Diamond Switch.—What is called a **diamond switch** in trackwork is a double crossover, such as is shown in Fig. 42 (*a*), (*b*), and (*c*). The laying out of a diamond switch is similar, as far as the calculation is concerned, to the laying out of a turnout switch. The distance between the opposite switch points measured on the straight rail is found in the same manner as the distance between the point of switch and the point of tangency in the turnout, formula **2**, Art. **70**. A simple method of laying out a diamond switch and one that is often used in mine work, especially where track room is limited, is as follows:

Through a central point a, Fig. 42 (*a*), midway between the two tracks, draw two straight lines at right angles to each other, each making an angle of 45° with the track rails. Extend these lines until each intersects lines drawn through the points of switch c_1, c_2, c_3, c_4 to which the latches come, if used, and at right angles to the track rails at these points. These intersecting points are the centers of the turnout



57 FIG. 42

curves, and are marked d_1, d_2, d_3, d_4, respectively. Where the diagonal lines cross the inner rails of the two tracks, b_1, b_2, b_3, b_4 are the main-rail frog points.

It is evident that, in this construction, according to the distance between the track centers, the diamond-frog points, at each side of the diamond, will lie between the two tracks, as shown in Fig. 42 (*c*), or they will be coincident with the two inner rails of these tracks, as shown at (*b*), or they will lie within the track rails, as shown at (*a*). The position of these frog points depends on the length of the crossing or the distance between the opposite switch points measured on the main rail, as compared with the distance between the track centers.

73. Precautions in Laying a Turnout.—In laying out a siding or parting on the haulage way, a number of points must be considered to insure the safety of the men and mules, if animal haulage is used; and also to enable the trips to be handled speedily. Ample width must be given to the turnout to allow the men and mules to pass between the two tracks and also between the tracks and the ribs. The parting should be of sufficient length to handle the longest trip that is hauled in the mine, or where a single track is used, the parting may sometimes be made long enough for two trips going in one direction to wait while a third going in the opposite direction passes, although this is not an economical arrangement. All switches should be carefully laid so as to provide, as far as possible, against the cars getting off the track and thus delaying the entire haulage system. The roof above the turnout should be thoroughly timbered in order to prevent falls of roof, which would endanger the lives of the workmen and would interfere with the haulage.

INDEX

NOTE.—All items in this index refer first to the section and then to the page of the section. Thus, "Advantages of diamond drill, §34, p78," means that advantages of diamond drill will be found on page 78 of section 34.

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