A TEXTBOOK

ON

MINING ENGINEERING

INTERNATIONAL CORRESPONDENCE SCHOOLS
SCRANTON, PA.

ECONOMIC GEOLOGY OF COAL
PROSPECTING FOR COAL AND LOCATION OF OPENINGS
SHAFTS, SLOPES, AND DRIFTS
METHODS OF WORKING COAL MINES
MECHANICS
STEAM AND STEAM-BOILERS
STEAM-ENGINES
AIR AND AIR COMPRESSION
HYDROMECHANICS AND PUMPING

WITH PRACTICAL QUESTIONS AND EXAMPLES

1007

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A–2

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ECONOMIC GEOLOGY OF COAL.

SURFACE AND STRUCTURAL GEOLOGY.

INTRODUCTION.

1278. Economic Geology is that department of natural science which treats of the structure of the earth's crust in its relation to its mineral products.

1279. The Economic Geology of Coal treats of the deposition, formation, and occurrence of coal, the shape and character of the coal deposits and their accompanying strata, and the nature and the history of the adjacent formations, as far as it will assist in mining.

It is as important that practical men should know what strata do *not* contain coal, as to know what strata do; therefore, we will briefly describe the formations below and above the coal measures.

1280. Dynamic Geology treats of the natural forces that operate in changing and modifying the structure of the earth's surface. These forces are known as *atmospheric, aqueous, igneous*, and *organic*.

1281. Atmospheric action disintegrates rocks and forms soil.

1282. Aqueous action, or the action of water, is either mechanical or chemical. Rivers, oceans, and ice exert mechanical force, and mineral waters cause chemical changes.

1283. Igneous action, or the action of heat, aids in the elevating of and the depressing of the sea bottom, and in the production of the inequalities of the earth's surface. All crust motion is due to the interior heat of the earth.

1284. Organic action was the cause of vegetable accumulations, forming coal and bitumen, and of animal accumulations, forming limestones.

1285. In Fig. 352 is shown an ideal section of the earth's crust. The references are as follows:

A, Recent Formations; *B*, Quaternary Formations;

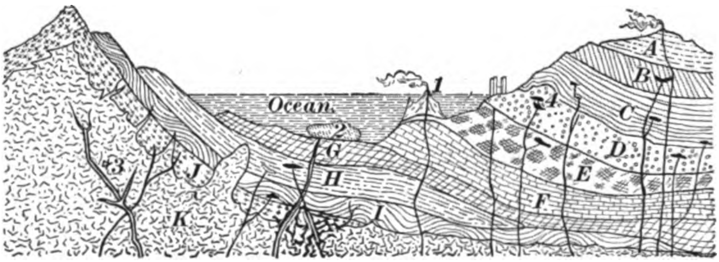

FIG. 352.

C, Tertiary; *D*, Mesozoic; *E*, Carboniferous; *F*, Devonian; *G*, Silurian; *H*, Cambrian; *I*, Pre-Cambrian; *J*, Laurentian; *K*, Molten and Igneous Rocks. *1*, Coral Reef; *2* and *3*, Granite Intrusion; *4*, Laccolite.

THE EARTH'S CRUST.

1286. The outer surface of the earth is a cool crust covering and enclosing incandescent matter in the interior. This crust consists of a solid structure with an irregular surface, consisting of mountains, plains, and valleys. The deepest depressions are filled with water and form the oceans and lakes.

1287. The mean temperature of the whole earth's surface is about 58° Fahrenheit, the northern hemisphere being about 60° Fahr., and the southern hemisphere 56° Fahr. There is in every locality a daily and an annual variation of temperature. The depth at which there is *no daily variation* is but a foot or two below the surface, but the depth of *invariable* temperature in temperate climates is about 60 or 70 feet. At the equator the depth of *invariable* temperature is only one or two feet from the surface. In high latitudes, approaching the poles, the depth of invariable temperature increases and probably exceeds 100 feet. Beneath the depth of invariable temperature the temperature of the rocks increases for all depths to which it has been penetrated. This rate of increase, however, is not uniform in all localities. It is sometimes faster in one locality than in another, all depending on the conductivity of the rock penetrated. Observation has given us the fact of increase, but no law. The following formula gives results conformable with the general results of observations:

$$T = 50.68 + \frac{D - 19.68}{67.2}, \qquad (83.)$$

where T = temperature in degrees Fahrenheit;
D = depth penetrated.

The mean density, or specific gravity, of the earth, as a whole, has been determined by several different methods at about 5.6, considering the density of water as 1. The density of the materials forming the earth's surface, leaving out water, is not more than 2.5. It is evident, therefore, that the density of the central portion must be more than 5.6.

STRATIFIED ROCKS.

1288. Stratified, or sedimentary, rocks consist, for the most part, of sand and mud thrown down originally either at the mouths of rivers along the sea-shore or in lakes. The materials vary greatly in degrees of fineness. The coarsest is a mass of rounded pebbles formed along a rocky shore. When these shingle pebbles are cemented together by a fine material they form conglomerate. Sand beds are composed of minute, loose, angular stones, accumulated before their corners were rounded. Gravel consists of loose rounded stones, or pebbles. Breccia consists of angular stones consolidated.

Stratified rocks are of three kinds, *arenaceous*, *argillaceous*, and *calcareous*, and a fourth, *organic*, may reasonably be added.

1289. **Arenaceous** rocks, in their incoherent state, are sand, gravel, shingle, rubble, etc., and in their

1296. These arenaceous, argillaceous, calcareous, and organic materials, or sands, clays, lime, and vegetable matter, may gradually combine with each other to form the argillaceous sandstones, calcareous sandstones, calcareous shales, marl, and organic shales.

There is abundant and conclusive evidence that stratified rocks are more or less consolidated sediments. Beds of clay and mud, and sand, may be traced, by almost insensible gradation, into shale and sandstone.

The cementing material, such as carbonate of lime, silica, or oxide of iron, present in percolating water, accounts for the consolidation of sediments into rocks.

In many cases rocks have been deposited with extreme slowness. In proof of this statement, shales are found the lamination of which is beautifully distinct, although each lamina is no thicker than cardboard. Each lamina was separately formed by alternating conditions, such as the rising and falling of tides or the flood and fall of rivers.

1297. Stratified rock must have been originally nearly horizontal, as such a position would naturally be assumed by all sediment in obedience to the law of gravity. It may, therefore, be assumed that highly inclined or folded strata have been changed since first deposited and consolidated. The planes separating strata were not originally all horizontal, nor was each stratum always of uniform thickness. Each stratum, when deposited, should be regarded as a widely expanded cake, thickest in the middle and thinning out at the edges, and interlapping there with similar cakes. In Fig. 353, *c* is sandstone and conglomerate, and *b* is limestone.

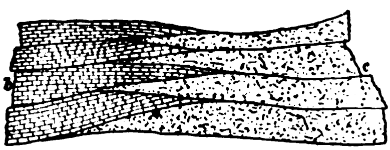

FIG. 353.

In fine materials, strata assume the form of extensive thin sheets, while coarse materials thin out more rapidly, and are more local.

The oblique lamination is a most important exception to the law of horizontality, and is considered a phenomenon.

Oblique lamination is due to rapidly shifting currents bearing lots of coarse materials, or to chafing of waves on an exposed beach. Fig. 354 is an example.

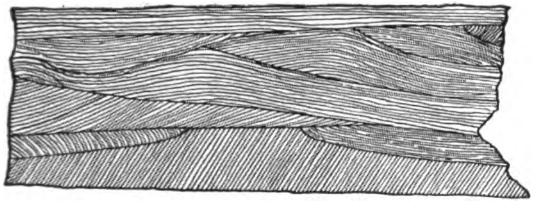

FIG. 354.

1298. Elevated, Inclined, and Folded Strata.—Assuming that stratified rocks were deposited as sediment at the bottom of water in a nearly horizontal position, it is evident that some great force has been at work changing the position of the rocks composing the earth's crust. These rocks are found in the vicinity of the oceans, but more often in the interior of the continents, high up on the mountains; sometimes they are horizontal, though high up; sometimes the strata at this elevation are still soft, but, as a rule, of a stony nature. In the mountain regions the strata are tilted at all angles, folded, contorted, overturned, broken, and slipped, so that it is difficult, in many instances, to determine their original order of superposition.

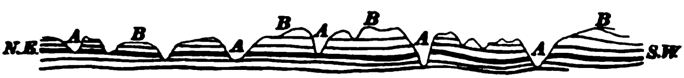

FIG. 355.

The outlying coal fields of Western Pennsylvania show clearly how strata, high up in the mountains, are found in a nearly horizontal position. (See Fig. 355.)

1299. Dip and Strike.—The dip of strata is their inclination from a horizontal plane. Fig. 356 shows strata dipping southward about 45°. The angle of dip is measured by a clinometer, and the direction of dip by a compass. The two instruments are often conveniently combined in one.

The strike of strata is the line of intersection of the strata with a horizontal plane. It is always at right angles to the

When strata terminate abruptly in a bold, bluff edge, they form an **escarpment.**

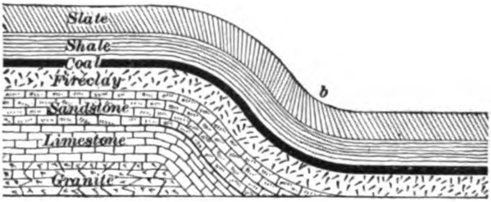

FIG. 360.

When any strata can be seen at the surface, the exposure is called the **outcrop.**

1302. Conformity and Unconformity.—When strata lie upon each other in parallel order, as at *d*, Fig. 358, they are termed **conformable;** but when one set inclines upon another at a different angle, they are termed **unconformable.** (See *d* and *f*, Fig. 358.) When strata are bent and twisted, they are termed contorted. (See *c*, Fig. 358.)

1303. Geological Formation.—A group of strata conformable throughout and containing similar fossils or organic remains, and separated from other conformable groups by a line of unconformable rocks, is called a **geological formation.**

1304. Concretions.—There is a chemical process common in stratified rocks which results in the formation of **nodules,** or **concretions.** For example, the flint nodules in chalk are due to the presence, among the chalk, of small shells, sponges, etc., which were chemically acted upon by percolating water and formed into flint nodules.

In many stratified rocks, nodules of various kinds are found, scattered through the mass, or in layers, parallel to the planes of stratification, or in groups, sometimes so thickly deposited as to form local patches of stone or gravel beds. The structure, like slaty cleavage, is the result of internal changes subsequent to the sedimentation, for the planes of stratification frequently pass through the nodules. The clay iron-stone nodules of the coal strata are familiar illustrations of this structure.

These nodules, or concretions, take quite a variety of shapes and are of all sizes up to many tons in weight. They frequently have a network of cracks inside, which may be

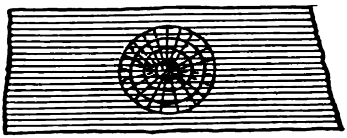

FIG. 361.

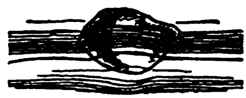

FIG. 362.

filled with different minerals. In coal beds, they are the nigger-heads and sulphur balls. In shales, there may be nodules of siderite or clay iron-stone. In limestone, the nodules are always silica. In sandstone strata, the nodules are commonly carbonate of lime or oxide of iron—lime or iron balls (Figs. 361 and 362).

The bending up and down of strata, quite locally, is sometimes due to the presence of large concretions, which, in process of formation, seem to have swelled the strata or pushed them away. (See Fig. 363.)

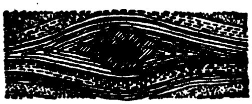

FIG. 363.

During the formation of coal, stumps and logs were floated off into lakes, to sink and become buried in the accumulating vegetable débris, or in deposits of detritus, and some of these stumps may have carried large stones which they finally dropped and so put an occasional "boulder" into the forming beds. These boulders must not be confounded with concretions.

ORIGIN AND DISTRIBUTION OF FOSSILS.

1305. Shells were imbedded in shore deposits, leaves and logs of high land plants and bones of land animals were drifted into swamps and buried in mud, and tracks were formed on flat muddy shores by animals walking on them. These have been preserved with more or less change. They are called **fossils.** There are multitudes of different fossils scattered through all the stratified rocks, but every group of rocks carries its own peculiar fossils, so that from the knowledge of them the truest key to the different formations is placed within our reach.

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Sand beds, mud beds, clay beds, pebble beds, and limestone beds all over different parts of the globe may have been forming during the same geological era.

A stratum of one age may rest upon any stratum in the whole series below it. For example, the coal measures may rest on the Archean, Silurian, or Devonian, and the Jurassic, Cretaceous, or Tertiary on any one of the earlier strata, the intermediate strata being entirely wanting.

The second object to be attained by classification is the division and subdivision of the whole series into larger and smaller groups, corresponding to eras, periods, and epochs of time.

The Geological Chart for North America gives an outline of the classification referred to. This classification is very important in the study of the Economic Geology of Coal.

UNSTRATIFIED, OR IGNEOUS, ROCKS.

1308. Igneous Rocks, which form the second class, are much more complex in structure and composition than aqueous, or stratified, rocks. They contain a great variety of minerals, and the minerals themselves are of great complexity. They are distinguished from stratified rocks by the absence of true stratification, by the absence of fossils, and by the difference in the mode of their occurrence. They are due to heat in some form.

1309. Igneous rocks occur underlying all the strata (see *K*, Fig. 352), forming the axes and peaks of nearly all

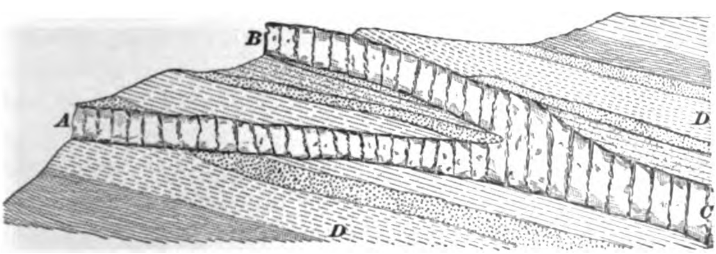

FIG. 364.

great mountain ranges (*J*, Fig. 352). They also occur in shapes. These cracks are called **joints.** In stratified rocks the plane between the bedding constitutes one of the three division planes, which is called the **bedding plane,** while the other two are nearly at right angles to the bedding plane and to each other. They are true joints, sometimes called slips, and are known among mining men as **butt cleat** and **face cleat.** In some stratified rocks one of these last joints is well defined while the other may be rather irregular. In Fig. 368 the face cleat is shown at *A*, the butt, or end, cleat at *B*, and the bedding planes at *D*.

Fig. 369 shows slips, or cleats, as they appear in different coals. They are: (*a*) Inclined cleavage; (*b*) vertical cleavage; (*c*) irregular cleavage; (*d*) rhomboidal cleavage; (*e*) cone-in-cone cleavage; (*f*) shelly cleavage.

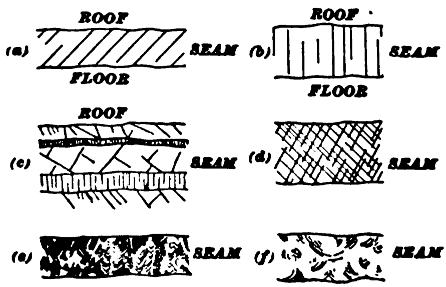

FIG. 369.

In sandstone, the blocks formed by these joints are large and irregularly prismatic; in slate, small, confusedly rhomboidal; in shale, long, parallel, straight; in limestone, large, regular, cubic.

In stratified rocks, these joints are all probably due to shrinkage in the act of consolidating from sediments, and in metamorphic rocks to shrinkage in cooling.

Fissures and fractures must not be confounded with joints; fissures are fractures in the earth's crust passing through several strata, instead of but one, as in the case of joints. Joints were probably produced by shrinkage and other causes, but fissures were produced by movements of the earth's crust.

1317. Cleavage.—Cleavage, in geology, has a different meaning from joints. Dana says: "Slates are often transverse to the bedding, that is, they often cross the layers of stratification more or less obliquely, instead of conforming to the layers, or bedding. Cleavage is, in this intermediate depressions by soil, so that the rocks are visible only at long intervals, as in (*d*), Fig. 372. Many of the difficulties in the study of rocks arise from this cause.

1327. In coal mining, the work of denudation is seen in wants or wash-faults, "pot-holes," etc. The latter (pot-holes) are deep hollows or excavations in the rocks, made by the grinding action of hard boulders agitated by turbulent water in the glacial period. Since formed, they have become filled in with stones, sand, and mud, and may be beneath rivers and lakes; hence the results of denudation sometimes seriously affect coal mining operations in an unexpected way. (Nanticoke, Pa., disaster in 1885.)

Denudation then is the opposite of deposition, but as deposition somewhere must go on at an equal pace with denudation there is no actual loss or waste of matter; it is simply the process of moving material from one place to another—tearing down one kind of rock to build up one of a totally different kind in a different locality.

1328. Another result or effect of denudation is that the accumulation of strata, composed of denuded older rocks, causes subsidence of the original crust over the area on which such new strata are deposited, and a corresponding elevation of the area denuded.

Applying this principle to mining, we may assume that the roof will cave in sooner, or to a greater extent, if a heavy culm pile exists over the worked area than if no culm were there to add to the weight. And where the floor is soft when the coal is removed, the bottom will rise, because the weight has been taken off it.

It does not follow that because a lower coal seam has been denuded locally, overlying ones will be similarly affected. This will usually depend upon what the want is filled up with; if with coal-measure material, then the upper seam will probably remain intact—undisturbed; but if sand, gravel, boulders, clay, etc., are there, the chances are the top coal is not there.

Extremely rare instances are on record of coal seams being denuded from underneath. Fig. 373 will illustrate what is meant.

In Belgium there are quite a number of open or empty pits, or a very deep kind of pot-holes traversing the coal measures, but they do not always extend upwards to the surface or even to the highest stratum of the coal measures.

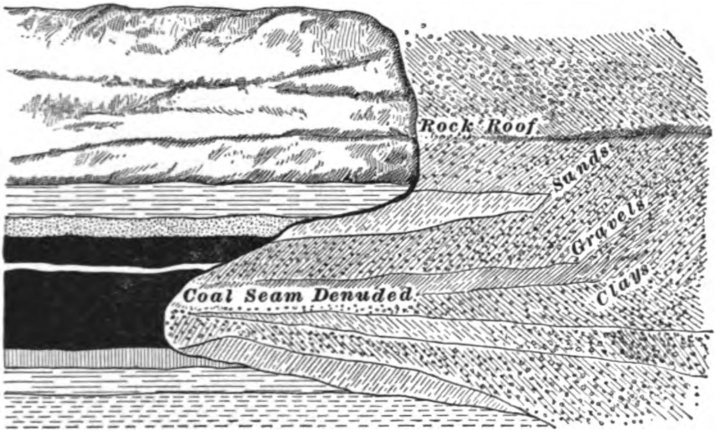

FIG. 373.

Some form of denudation would seem to have produced them.

1329. Thinning Away of Strata—Overlap.—It sometimes happens that two lines of outcrop come together, owing to the complete thinning away of the intermediate strata, and the conjoined outcrops may then be traceable for a long distance without further change. Instances of this kind sometimes occur among coal seams.

When the sea encroaches on the land, wearing away the cliffs and spreading out their waste materials in the form of shingle and sand upon the beach, the upper beds will spread over and cover up the lower ones.

This structure may frequently be met with along the margins of formations deposited in regions which at one time underwent gradual submergence.

HISTORICAL GEOLOGY.

PREHISTORIC ERAS.

INTRODUCTION.

1330. The earth's history is divided into geological eras, ages, periods, and epochs, and nature has recorded these in separate rock systems, rock series, rock groups, and rock formations. In geological history the eras and periods shade insensibly into each other; nevertheless, there have been times of revolutionary change. The divisions of time, especially ages, are characterized by the introduction and culmination of successive dominant classes of organisms, the highest expressions of earth life. Thus, we have an age of mollusks, an age of fishes, an age of reptiles, in which these were in their turn the dominant class.

Unconformity of the rock system and change in the life system are the two modes we have of determining and limiting eras, ages, periods, etc. Unconformity indicates blanks in the known record furnished by the rock system, rock series, and rock formations, but the most important changes in the life system of the eras, ages, periods, etc., ought to, and usually do, correspond with the unconformity of the rock system. When there is discordance, as there sometimes is, we should rather follow the life system than the rock system.

1331. There are five eras with corresponding rock systems in the earth's history, viz.: (1) Archean, or Eozoic (dawn of animal life), embodied in the Laurentian system; (2) Paleozoic (old life), embodied in the Paleozoic, or Primary system; (3) Mesozoic (middle life), recorded in the Secondary system; (4) Cenozoic (recent life), recorded in the Tertiary and Quaternary systems, and (5) Psychozoic (or era of mind), recorded in the recent system.

These grand divisions, with the exception of the last, are founded on almost universal unconformity of the rock system, and a very great and apparently sudden change

Lesley; the beds are numbered in accordance with their succession, beginning below, the lowest being given first:

		Feet.
A.	Millstone grit (sometimes called Farewell rock)	?
1.	Coal No. A, with 4 ft. of shale	6
2.	Shell and mud rock	40
3.	Coal No. B (of mammoth bed of central Pa.)	3–5
4.	Shale, with some sandstone and iron ore	20–40
5.	Fossiliferous limestone	10–20
6.	Buhrstone and iron-stone	1–10
7.	Shale	25
8.	Coal No. C, the Kittanning cannel	3½
9.	Shale—soft containing two beds of coal 1′–1½′	75–100
10.	Sandstone	70
11.	Coal No. D, Lower Freeport	2–4
12.	Slaty sandstone and shale	50
13.	Limestone	6–8
14.	Coal No. E, Upper Freeport	6
15.	Shale	50
16.	Mahoning sandstone	75
17.	Coal No. F	1
18.	Shale, thickness considerable	?
19.	Shaly sandstone	30
20.	Red and blue calcareous marlytes	20?
21.	Coal No. G	1
22.	Limestone, fossiliferous	2
23.	Slate and shales	100
24.	Gray clayey sandstone	70
25.	Red marlyte	10
26.	Shale and slaty sandstone	10
27.	Limestone, non-fossiliferous	3
28	Shales	32
29.	Limestone	2
30.	Red and yellow shale	12
31.	Limestone	4
32.	Shale and sand	30
33.	Limestone, with bands of spathic iron ore	25
34.	Coal No. H, Pittsburg	8.9

formed the humus or vegetable mold found in all forests. This substance would increase without limit were it not that its decay goes on simultaneously with its formation. But in peat bogs and swamps, the excess of water and, still more, the antiseptic property of the peat itself prevent complete decay. Thus, each generation takes from the air and adds to the soil continually and without limit. The soil which is made up entirely of this ancestral accumulation continues to rise higher and higher, until the bog often becomes higher than the surrounding country, and, when swollen by unusual rains, bursts, and floods the country with black mud. A bog is, therefore, composed of the vegetable matter of thousands of generations of plants. It represents so much matter drawn from the atmosphere and added to the soil. In such cases, besides the material deposited from the growth of vegetation, the accumulation may be partly also the result of organic matter drifted from the surrounding surface soil."

Peat is disintegrated and partially decomposed matter composed of carbon, with small and variable quantities of hydrogen, oxygen, and nitrogen.

Dana says: "There is no reason to suppose that the vegetation was confined to the lower lands; it probably spread over the whole continent (American Continent) to its most northern limits. It formed coal only where there were marshes, and where the deposits of vegetable débris afterwards became covered by deposits of sand, clay, or other rock material."

1346. The theory that coal has been accumulated by growth of vegetation *in situ*, as in peat swamps of the present date, is supported by the purity of the coal in some of the coal fields of America, the ash not being greater than would result from the plants of which it is composed. In extensive peat swamps, absolutely pure vegetable accumulations, unmixed with sediment, occur; but in buried rafts of drifted vegetable matter of any kind, there must be a large admixture of mud. The theory is further supported by the most complex and delicate parts of the plants, in their natural relation to each other, being preserved.

posited on top, and as far as it could reach (for depth of water and other conditions prevailing at the time) towards *A*. Then came the formation or accumulation of the upper

FIG. 376.

bench of coal right over the top of both coal at *A* and strata at *B*, and of course beyond, until conditions changed again.

In Staffordshire, England, the "Ten Yard" coal has been proved to split up in a N E direction into no less than ten separate seams of coal in 500 feet of strata, and this in a distance of only five miles.

Fig. 377 is a section of a 30-foot coal seam *C C* which is replaced by 60 feet of rocks and slates at *A B*. The lower

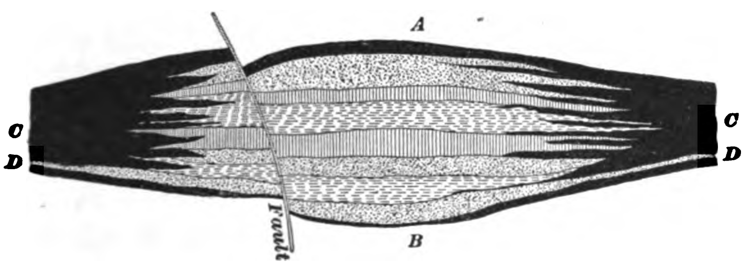

FIG. 377.

seam *D D* is also cut out and replaced at *B* by the same *horse*.

This horse measured 1,200 feet by 804 feet by 60 feet thick in the middle, tailing or thinning out on all sides to nothing.

1348. The Gradual Change from Wood to Anthracite.—To illustrate the gradual change in composition in passing from wood to peat, to lignite, to bituminous, and to anthracite, Dr. Percy gives the following table.

In this table Dr. Percy gives the proportions of hydrogen, oxygen, etc., to each 100 parts of carbon:

Kansas and Nebraska. The Illinois and Missouri areas are connected only through the Sub-Carboniferous rocks of the Carboniferous Age. But it is probable that formerly the coal fields stretched across the channel of the Mississippi, and that the present separation is due to erosion along the valley. Area, 98,000 sq. miles.

6. Acadian coal field, or the Nova Scotia and New Brunswick Area.—This is a large area on both sides of the Bay of Fundy. Estimated area, 18,000 sq. miles.

Besides these in the Carboniferous Age, there are the following barren, or nearly barren, areas:

1. The Rocky Mountain and Pacific Border region, embracing the Great Basin and Summit Area, containing parts of Montana, Wyoming, Colorado, Utah, and Nevada. Also, the California area in Northern California.

2. The Arctic Region, on Melville Island and other islands between Grinnell Land and Banks Land, on Spitzbergen and on Bear Island, north of Siberia.

Other American coal fields will be described when treating of the Cretaceous and other formations.

1350. Plication.—Coal seams and the strata containing them were originally horizontal and continuous; but they are now found sometimes horizontal and sometimes dipping at all angles, and folded in a most complex manner. In the Appalachian region, especially in the anthracite districts of Northeastern Pennsylvania, the strata are much disturbed and the coal seams interstratified with them are

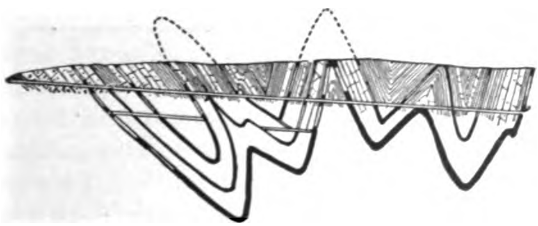

FIG. 378.

often nearly perpendicular, as shown in Fig. 378, which is a section of a coal basin at Panther Creek, Pa.

(the Permian), many leaves of record have been recovered, while in the other *intervals*, not a leaf of record has been discovered.

Until recently nothing of interest in the American Permian has been found, except a few shells, but Europe furnishes a larger number of fossils. Permo-Carboniferous furnishes coal in North America, Bohemia, and in France.

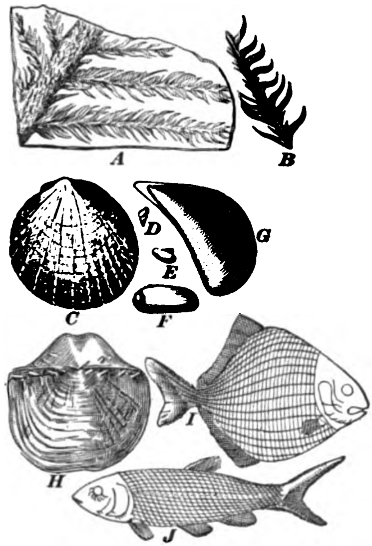

FIG. 382.

In Fig. 382 are shown specimens of the Permian fossils. They are:

A and *B*, walchia piniformis (Permian of Europe); *C*, eumicrotis hawni; *D*, gasteropod; *E*, bakewellia parva; *F*, pleurophorus subcuneatus; *G*, myalina permianar; *H*, pseudomonotis; *I*, platysomus gibbosus; *J*, restoration of paleoniscus.

MESOZOIC ERA, OR AGE OF REPTILES.

1356. This era is divided into three periods:

1. Triassic, because of its three-fold development where first studied in Germany.

2. Jurassic, because of the development of its strata in the Jura mountains.

3. Cretaceous, because the chalks of England and France belong to this period.

In Europe the Triassic formation is more distinctly separated from the Jurassic than in America, and they are, therefore, spoken of in this country as the Jura-Trias, or Triasso-Jurassic.

1357. Triassic.—See Jùra-Trias.

1358. Jurassic.—In the Jurassic are reproduced on a large scale the conditions favorable to luxuriant growth of formations, but, as a whole, they are less frequently metamorphic than the older rocks.

By referring to the Geological Chart for North America, it will be seen that the Cretaceous is divided into Upper and Lower, but it might conveniently be subdivided into Upper, Middle, and Lower. These subdivisions are local. In Europe, nearly everywhere, the Tertiary is unconformable on the Cretaceous, but in America, there is a transition period between the Cretaceous and Tertiary, called the Laramie; sometimes it is included in the Upper Cretaceous.

1364. Laramie-Cretaceous.—This, excepting the Carboniferous Age, contains the largest coal field in the United States and Canada.

1. Plateau Coal Field.—This valuable field covers most of the Laramie plains in Montana and Wyoming, and stretches into Utah. The area must be very great.

2. Coal Field of the Plains.—Of great area in Dakota, and extending into Assiniboia, Saskatchewan, Alberta, and Athabasca in British America. Area, enormous.

3. New Mexico Coal Field.

4. Kansas-Colorado Coal Field.—A large coal field covering the greater portion of Western Kansas and Eastern Colorado.

5. Pacific Coal Field.—This is comprised of the Seattle, Carbon Hill, and Bellingham Bay areas in Washington.

6. British Columbia Coal Field.—The Nanaimo coal areas of Vancouver's Island.

7. Californian Coal Field.—Monte Diablo and Corral Hollow areas in California.

8. The *Coahuila Coal Field.—Including all the coal areas on the Sabinas River, at Fuente and San Tomas, in the State of Coahuila, Mexico, and Eagle Pass, etc., Texas.

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*There is a doubt as to whether the Coahuila coal is Laramie-Cretaceous or Carboniferous.

As there are no coal formations of any value above the Laramie, it is scarcely within the province of Economic Geology of Coal to go into the more recent ages; but the leading fossils found in these recent formations are illustrated, as they are very useful as a guide to the prospector.

1366. Specimens of Tertiary fossils are shown in Fig. 387. They are as follows:

A, head of a sivatherium giganteum; *B*, tooth of zeuglo-

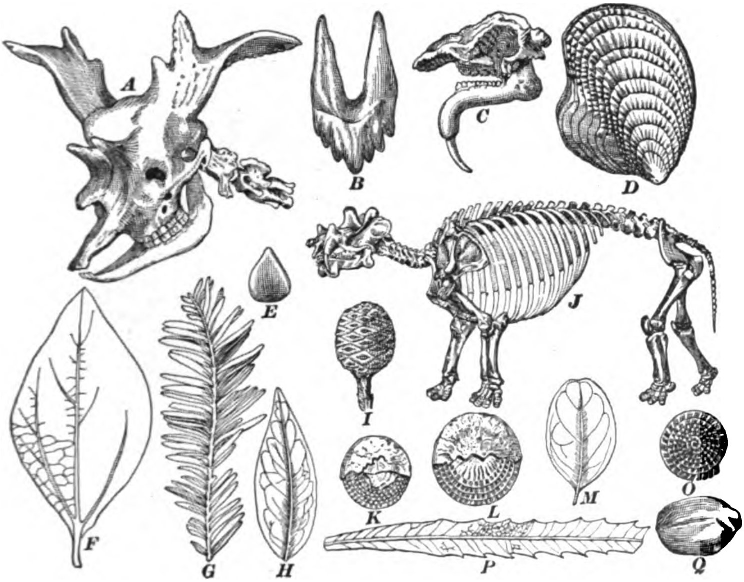


FIG. 387.

don cetoides; *C*, head of dinotherium giganteum; *D*, ostrea selleformis; *E*, fagus ferruginea, nut; *F*, cinnamomum mississippiense; *G*, leaf of sequoia langsdorfii; *H*, andromeda vaccinifoliæ affinis; *I*, fruit of sequoia langsdorfii; *J*, tinoceras ingens; *K*, *L*, *O*, nummulina levigata; *M*, quercus crassinervis; *P*, quercus saffordi; *Q*, carpolithes irregularis.

1367. Specimens of Quaternary fossils are shown in Fig. 388. They are:

A, mammoth (elephas primigenius), skeleton; *B*, tooth of repeated many times. A section of the South Joggins coal field, Nova Scotia, shows eighty-one coal seams, but only a few are workable. In Westphalia, Germany, there are 117 seams. The aggregate thickness of all the seams in

Lancashire is 150 feet.
Pottsville, Pa., is 113 feet.
Western Coal Fields is 75 feet.
Westphalia is 274 feet.
Mons, France, is 250 feet.

The great anthracite region of Pennsylvania is largely Lower Carboniferous or lower coal measures. However, in a deep trough in the otherwise nearly horizontal outspread of Catskill formation, the coal measures of Carbondale, Scranton, and Wilkes-Barre have been preserved. They cross Luzerne County so deep in this trough that it has retained not only the *lower* and *middle*, but the upper coal beds, above the Pittsburg bed, and even a remnant of still higher rocks (containing Permian fossils).

The greatest development of the lower coal is in Pennsylvania, and of the upper in the States further west. The highest beds of the series appear to occur west of the Mississippi, in Kansas, where they merge into the Permian.

The following is a section (by J. P. Lesley) of that part above the Pittsburg bed (see Art. **1342**) in Waynesburg, Green County, Pa.:

		Feet.
1.	Shale, brown, ferruginous	30
2.	Sandstone, gray and slaty	25
3.	Shale, yellow and brown	20
4.	Limestone—the great limestone south of Pittsburg (including two coal beds, 2½ feet and 1 foot)	70
5.	Shale and sandstone	17
6.	Limestone	1
7.	Shale and sandstone	40
8.	Coal	6
9.	Shale, brown and yellow	10
10.	Sandstone, coarse brown	35

of 15 to 36 per cent. of water. The amount of hydrogen in each is from 4 to 7 per cent. Both have a usually bright, pitchy, greasy luster (whence often called Pechkohle in Germany), a firm, compact texture, are rather fragile compared with anthracite, and have a specific gravity of 1.14 to 1.40. The brown coals have often a brownish-black color, whence the name, and more oxygen, but in these respects and others they shade into ordinary bituminous coals. The ordinary bituminous coal of Pennsylvania has a specific gravity of 1.26 to 1.37; of Newcastle, England, 1.27; of Scotland, 1.27 to 1.32; of France, 1.2 to 1.33; of Belgium, 1.27 to 1.3. The most prominent kinds are the following:

1374. 3. **Caking Coal.**—A bituminous coal which softens and becomes pasty, or semi-viscid, in the fire. This softening takes place at the temperature of incipient decomposition, and is attended with the escape of bubbles of gas. On increasing the heat, the volatile products, which result from the ultimate decomposition of the softened mass, are driven off, and a coherent, grayish-black, cellular, or fritted mass (coke) is left. Amount of coke left (or part not volatile) varies from 50 to 85 per cent. Byerite is from Middle Park, Colorado.

1375. 4. **Non-Caking Coal.**—Like the preceding in all external characters, and often in ultimate composition; but burning freely without softening or any appearance of incipient fusion.

1376. 5. **Cannel Coal** (Parrot Coal).—A variety of bituminous coal, and often caking; but differing from the preceding in texture and to some extent in composition, as shown by its products on distillation. It is compact, with little or no luster, and without any appearance of a banded structure; and it breaks with a conchoidal fracture and smooth surfaces; color, dull black or grayish-black. On distillation it affords, after drying, 40 to 66 per cent. of volatile matter, and the material volatilized includes a large proportion of burning and lubricating oils, much larger

GLOSSARY.

1382. *Acrogens.*—Consist of vascular tissue in part and grow upwards; as (1) ferns; (2) lycopods (ground-pine); (3) equisetæ; and include many genera of trees of the coal period.

Age.—(1) Any great period of time in the history of the earth or the material universe, marked by special phases of physical condition or organic development; as, the Age of Mammals. Called also *era.* (2) One of the minor subdivisions of geological time, a subdivision of the epoch and correspondent to the stage or formation; recommended by the International Geological Congress. See Geological Chart for North America.

Amphibians.—Animals capable of living both on land and in water, like the frog.

Antiseptic.—Opposed to or counteracting decay.

Araucarian.—A genus of fossil trees of the pine family (coniferæ) represented by trunks (often of great size), and closely allied to araucaria, a genus of large evergreen trees of the pine family.

Arborescent.—(1) Having the nature of a tree; tree-like in appearance or size. (2) Branching like a tree.

Articulates.—Consisting (1) of a series of joints or segments; (2) having the legs, when any exist, jointed; (3) having the viscera and nervous cord in the same general cavity; (4) having no *internal* skeleton, as worms, crustaceans, insects.

Brachiopods.—See definition of Foraminifera, and also *22 a*, *22 b*, *23 a*, *23 b*, and *29*, Fig. 374.

Bryozoans.—Moss animals, so named with reference to the moss-like corals they often form. The corals consist of minute cells either in branched, reticulated, or encrusting forms. They are often calcareous; and as such were common in the Silurian Age, and still occur.

Buhrstone (Burrstone).—A cellular but very compact silicious rock from which the best millstones are made.

Crystalline.—Composed of angular grains or particles more or less crystallized in place.

Culmination.—The highest point, condition, or degree of achievement; as the culmination of life.

Cycads.—A family of palm-like or fern-like plants with unbranched stem bearing a crown of feather-like leaves, rolled inwards from the apex in a coil.

The Cycadaceæ embrace 9 genera and 75 species, chiefly of the Southern Hemisphere.

Débris.—An aggregation of detached fragments of rocks, whether *in situ* at the base of its original cliff, or heaped up after transportation (drift in part).

Delta.—An alluvial deposit formed at the mouth of a river; so called from its frequent resemblance to the fourth letter delta (Δ) of the Greek alphabet.

Detritus.—(1) Loose fragments or particles of rock, whether angular or water-worn, especially the latter. (2) A mass of disintegrated material of any kind; rubbish; waste.

Dominant.—Conspicuously prominent in point of numbers.

Dyke.—A mass of igneous rock filling a fissure in other rocks into which it has been intruded.

Echinoderms.—Animals having their exterior more or less calcareous and often furnished with spines; and having distinct nervous and respiratory system and intestines, as starfish, crinoids, etc.

Encrinites or Crinidea.—Having a regular radiate structure, and arms proceeding from the margin of the disk; also, a stem consisting of calcareous disks, by means of which, when alive, they are attached to the sea bottom, or some support, so that they stand in the water and spread their rays like flowers, the mouth being at the center of the flower.

Epoch.—The chronological subdivision of geological history of the third order; as the Hamilton *epoch.*

The corresponding stratigraphic division proposed by the and mica intimately intermixed, and having the mica foliated or disposed in parallel planes, producing a moderate tendency to cleavage into thick slabs; thus distinguished from *granite.*

Graphite.—This is simply carbon, neither lead nor iron occurring in the pure mineral. It is often called plumbago and black lead (the material of lead pencils), and looks like a metallic substance.

Group.—In stratigraphical classification of stratified rocks, the division next below the system or series: (1) In general usage, the chief subdivision of the system, in the ordinary application of that word, as the Chemung *group* of the Devonian system. (2) In the official usage of the U. S. Geological Survey, one of the chief subdivisions of a system (*system* being applied to the grander divisions of geological history), based mainly upon paleontological distinctions, but also upon structural separateness, as the Devonian *group* of the Paleozoic system (age). Under this usage *formation* replaces the word *group* in its more common application. (3) In the scheme proposed by the International Congress of Geologists, the highest stratigraphic division, corresponding with *era*, the highest chronological division.

Gulf Stream.—A great ocean current flowing from the Gulf of Mexico northward nearly parallel to the Atlantic coast of the United States, and turning eastward off Nantucket Island, its average rate being about two miles per hour. It plays an important part in ameliorating the climate of Great Britain and Norway. The similar Japan current, or *Kuro-Shiwo,* which gives a warm, moist climate to the lower Alaskan coast, is sometimes called the *Gulf Stream* of the Pacific.

Heteropod.—One of the family of gasteropods.

In situ.—In its original or proper site or position.

Invertebrate.—Not having a backbone.

Laccolite.— A mass of intrusive lava, which spreads out

PROSPECTING FOR COAL AND LOCATION OF OPENINGS.

PROSPECTING.

PRELIMINARY EXAMINATIONS.

1383. Prospecting is a practical application of geological knowledge for the purpose of determining whether coal or any other useful mineral may be found in any particular locality.

In prospecting for coal a *general* knowledge of all formations, and a *special* knowledge of coal-bearing formations, are required.

1384. Preliminary Considerations.—Before beginning to prospect extensively the following points should be considered: 1. Is the location of the tract such as to enable shipments to be made in an economical manner; that is, are there rail or water facilities immediately available, or, if not, is there a reasonable prospect of rail facilities in the near future? 2. What competition must be met in available markets, and what advantage, if any, will coal from the tract in question have in those markets? 3. Is there an abundance of labor near the tract, or can sufficient labor be brought there from other fields? If these questions, more particularly the first two, can be answered satisfactorily, the work of prospecting should begin.

1385. Preliminary Work.—Searching for coal in an unprospected region should first be done in a general way, and secondly in a more particular manner. The prospector should first go over the ground, carefully noting all map should be on as large a scale as is convenient. Thus, for a tract of land of two miles square, a scale of 400 ft. per inch would be as large a map as could be conveniently used in the field. For larger tracts a much smaller scale is advisable. This scale is so small that to make notes directly on the map, in the field, requires great neatness and care on the part of the prospector, and also the use of conventional signs to designate certain features, so as to prevent the confusion and illegibility of written notes. Fig. 391 shows a number of conventional signs most frequently used by prospectors.

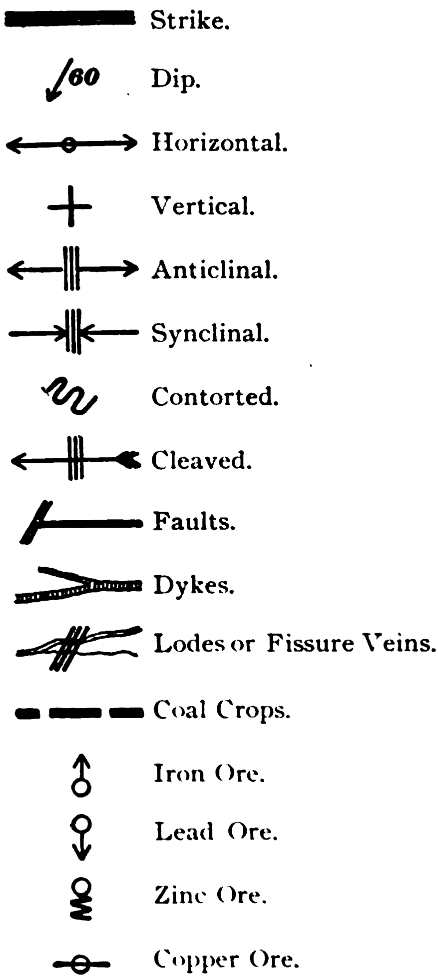


FIG. 391.

1389. Object of First Examination.—The first general examination of a tract is to determine the *character* of the rock beds. Their extent may be shown, approximately, on the map. Every care must be taken to determine rightly the relative ages of the beds, for on this the results of the prospect almost wholly depend. The means by which the relative ages may be determined have been described in Economic Geology of Coal.

the seam. In the case of bituminous coal the blossom is a soft, black, sooty mixture of coal and clay.

Where the blossom has slipped, a prospect trench about two feet wide is advanced by stages into the hillside, as shown in Fig. 393. The trench may be started at any point below the bench where the prospector's judgment may indicate, or it may advantageously be started on the bench's level. If it shows no indication of coal after it has been advanced to the upper side of the bench (see *a*, Fig. 393),

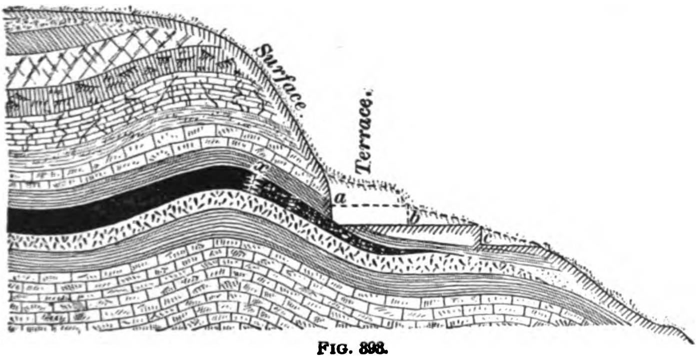


FIG. 393.

a second trench *b* may be started at a lower point and carried up to the place at which the first trench began.

In case the second trench, shown in the figure as *b*, proves barren, a third trench *c* may be started still further down the hill, and be driven up to the beginning of trench *b*. In like manner any number of trenches may be driven. If all the trenches prove barren, any one, as trench *b* for example, may be continued to the point where trench *a* was discontinued. If this trench should find the outcrop, a drift following the crop coal should be driven till the true coal is met at *x*.

It frequently happens that the lowest trench shows the blossom running up, in which case the trench simply follows the indications of coal, which grow stronger until the solid or full face of coal is shown. If only a trace of coal is found by digging these trenches, and the indications or judgment prompt the prospector to go further into the hillside, the trench is turned into a *drift* by widening it so that a wheelbarrow or a car can be taken in. If these proceedings should give an unsatisfactory result, the trench, or it may be a drift now, should be turned into a prospect shaft and sunk until some trace of coal is reached. If, after sinking a reasonable depth, the result is still negative, it only remains to repeat the experiment at a higher or lower elevation on the hillside at some distance to the right or left of the first trench. The fact of having found no coal, or no trace of coal, is only proof that the material in which the former trench was made has been brought down from the hillside above by a landslide, sweeping before it all traces of the bed. This is very frequently the case with the outcrop where there is a bold escarpment or bluff above it, such as is present in the Cumberland mountains in the form of a conglomerate 20 feet to 80 feet thick, or more, overlying the shales covering the lower coal measures. The shale disintegrated, thus undermining the conglomerate to such an extent that it settled and slid down hill, pushing the strata overlying the coal away down the mountain. Sometimes this slip carried several yards of the seam of coal intact with it, which when first struck by the prospector was very misleading. Where surface indications "give out," a great advantage, which saves much money in locating the outcrop, is secured by running a line of levels from a point where the coal has been opened up to the point where another exposure of the coal is desired. If the coal has a dip, it should be taken into consideration when running this line of levels.

1397. Presumptive Evidence of Coal.—If the surface examination yields no evidence of the presence of coal other than rocks of the Carboniferous or later coal-bearing ages, the existence of coal in the tract is still probable, and boring is resorted to. But it is seldom necessary to bore holes to prove the near existence of coal, for, if the surface examinations are carefully made, unmistakable evidence of its presence will generally be discovered.

It must be distinctly remembered that coals which have an outcrop are now being discussed.

1398. Influence of Slip of Blossom on Thickness of Bed.—The creep, or slipping of the blossom, down hill, when *away from the bed*, will seldom cause the crop to present an exaggerated thickness in a prospect trench or shaft (see *a*, Fig. 394); but when the bed dips with the hill slope, the crop is usually overturned down hill, and the blossom is thus turned over on the outcrop (see *b*, Fig. 394). A prospect shaft sunk through such an overturned outcrop would deceptively indicate the presence of a bed much thicker than the actual measurement of the seam. The prospect shaft should, therefore, be sunk through the entire

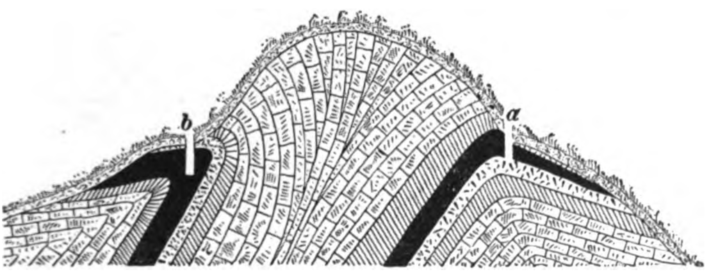


FIG. 394.

thickness of coal until the bottom clay or slate is reached, and then widened out horizontally, or a level should be driven at right angles to it, until the top rock is encountered. When two sets of cleavage planes cross the coal at nearly right angles, or where the outcrop is twisted and contorted by a creep or slide, it may be difficult to distinguish the roof from the floor, on account of the small area of the seam exposed in a prospect opening, and the direction of the dip remains uncertain. The occurrence of stigmaria—the roots of sigillaria—in one of the rock walls of the seam is presumptive evidence that the stratum containing them is the bottom of the seam. But if sigillaria, fern leaves, etc., are found, the rock is probably the roof or top rock, although both of these fossil plant remains may occur in either the roof or bottom of a coal seam.

edges. Thus, we have long slopes ending in long horizontal

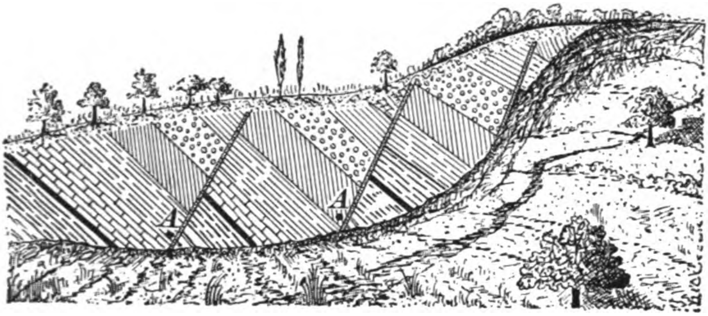


FIG. 395.

gangways, which in turn give way to rising headings or a slope from the opposite side. (See Fig. 396.)

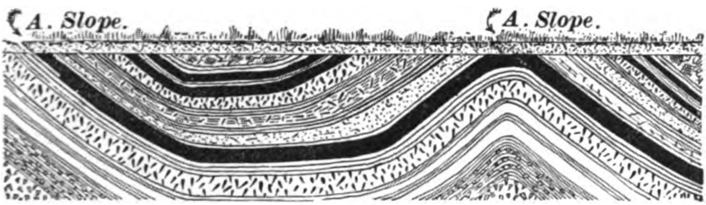


FIG. 396.

1401. Oblique Lamination.—In measuring the dip care must be exercised that oblique lamination, cleavages, or other indications of cross-fracture, and layers displaced by the growing roots of trees, are not mistaken for the true dip of the seam.

1402. True Dip.—While studying the rock bed, the true dip must be carefully determined. There is a great advantage in being able to get a full view of a bed of rocks, inasmuch as the true position of any one of these rocks, when met singly, as well as the position and thickness of the others, if they are not exposed, may be inferred. Every change of the dip deserves attention regarding amount, direction, etc. Such change may be only local, or superficial, instead of belonging to the great and regular bending of the rock. When one fold dies out and another begins at the same time to rise on one side or the other, The end of the base line should be carefully marked by some prominent object, such as a piece of heavy **T** rail, or an old car axle, when obtainable, about 3 feet long, driven into the ground, the "point of sight" being carefully marked by a cross (+) mark; or a large-sized stone may be sunk in the ground and a hole drilled in the same at the "point of sight."

Special care must be taken to avoid ill-conditioned angles, that is, triangles should be avoided with angles less than 30° or more than 120° to 150°, because a point is not absolutely defined if the lines fixing it meet at a very obtuse or very acute angle.

The completion of a survey by triangulation is accomplished by the "filling in" of the interior details by surveying, with the transit or compass, the rivers, roads, woods, streams, etc.

1411. Preservation of Notes.—All notes should be carefully preserved either on the plan constructed for the prospector's final examination, or, what is better, in a substantially bound book, so that should the examination of the property develop sufficient facts indicative of successful mining, a working map or colliery plan can be constructed from them.

In order to show the application of what has been said in the preceding articles, two diagrams are given (Figs. 398 and 399).

1412. Prospector's Map.—In Fig. 398 is shown the manner in which data is compiled and recorded on a prospector's map. The shaded parts show what is actually seen by the prospector; over the blank portion he is supposed to have been unable to see any rock in place.

Most all the observations occur along the streams, these being the most frequent natural lines of section. At each point where the dip has been taken an arrow and number mark the direction and angle of dip. The more important or stratigraphically serviceable beds have their outcrops marked in decided lines where actually seen. The outcrop, where the same stratum can be seen in two adjacent streams, may be drawn across the intervening ground, and the intervening ground should be searched for corroborative indications.

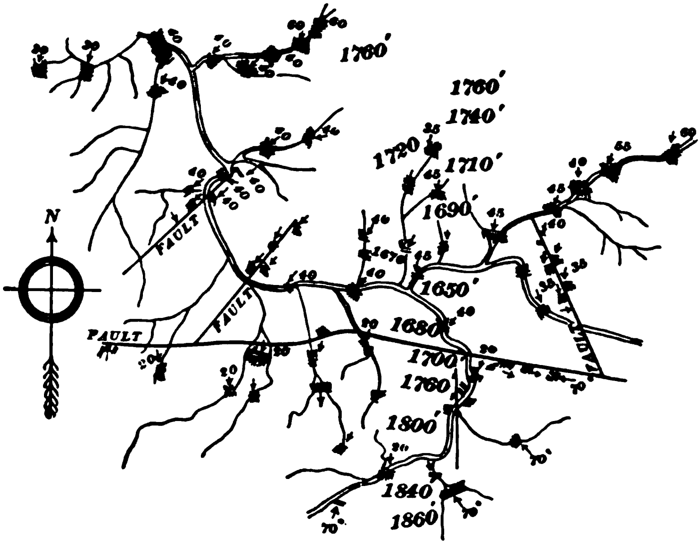


FIG. 398.

The outcrop may be drawn in continuous lines on the plan where there is no doubt regarding its position and direction, but where any doubt exists regarding these points it must be indicated only by dotted lines.

1413. Fig. 399 shows a complete geological plan constructed from the prospector's notes shown on Fig. 398. It will be noticed that the order of succession of the rocks is found to be the same in the different streams. Bed *a*, after an interval, is followed by *b*, *c*, *d*, *e*, *f*, and *g*, but at *h* a fault is met, which throws the stratum *a* to the position shown at *i* (see map and section), which, after an interval, is followed by *j*, *k* (*j*, *k* are the same beds as *b*, *c*), but at *l* something different is met, viz., the same rocks dipping in the opposite direction. The result is plainly shown in section, Fig. 400. Where a blank space occurs, and owing to some surface accumulations a certain bed may not be visible to the pros-

(Fig. 402). A section is sometimes found where the two lines of outcrop come together, caused by the complete thinning away of the intermediate strata. In this case the

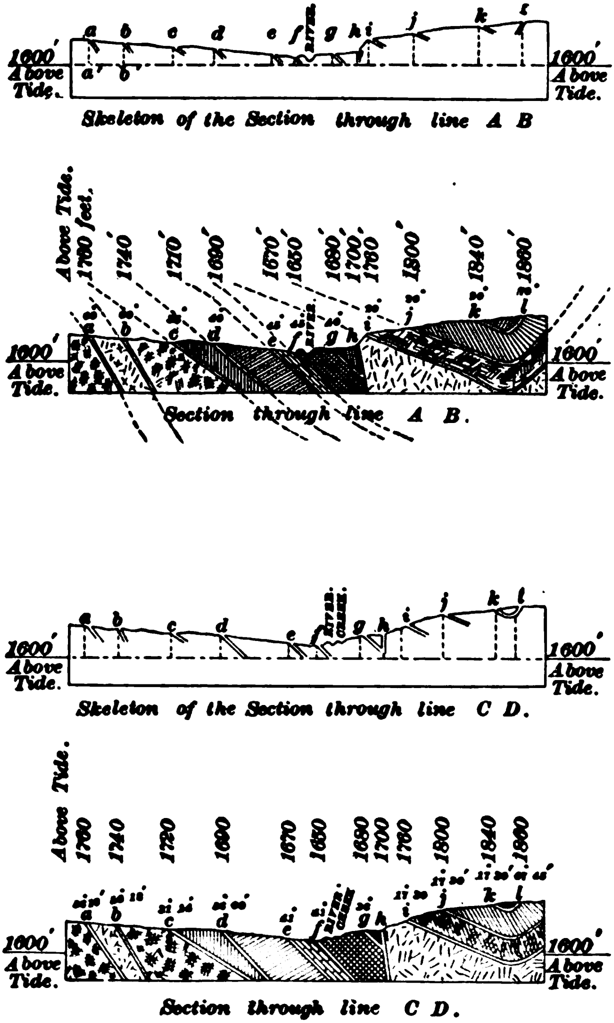


FIG. 400.

conjoining outcrops may be traced for a long distance without any change. The higher portions of a series of strata now and then steal or lap over the lower.

Such a formation can not always be shown on the map, but it is made clear by a section. This structure (see Economic Geology of Coal) may frequently be met with along

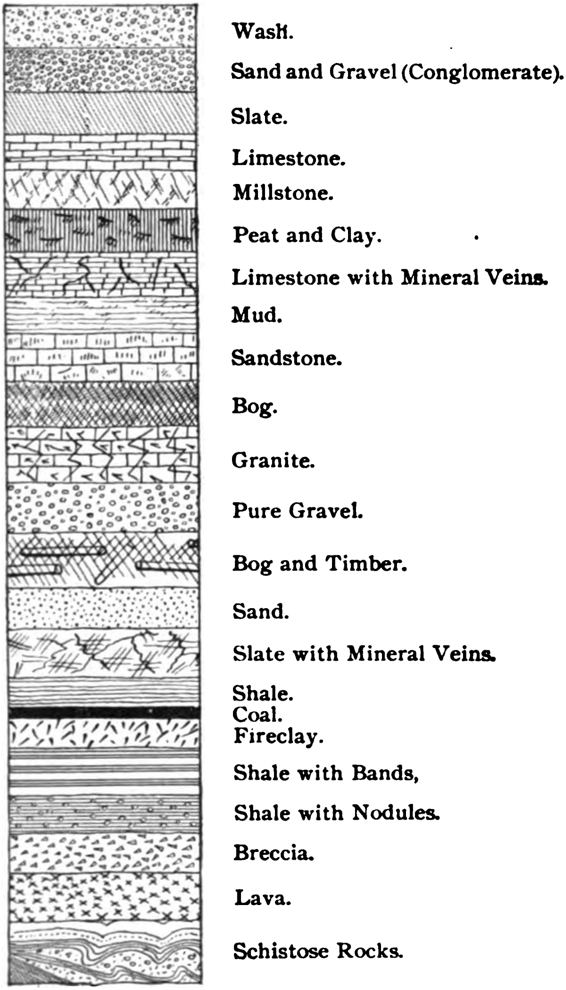


FIG. 401.

the margins of formations deposited in tracts which were undergoing gradual submergence. The strata are parts of one continuous and unbroken series. As the land sank, successive formations were carried down beneath the sea, and the later deposits of the sea floor were prolonged

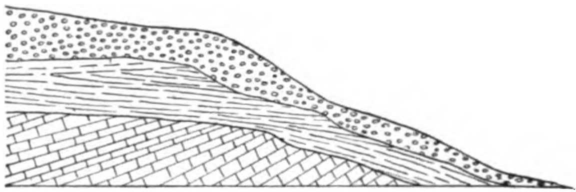


FIG. 402.

further and further beyond the limits of the earlier one. No apparent unconformity can be detected between any portions of them. But where the accumulation of a group has been succeeded by elevation, exposure, and denudation, the next set of strata laid down on this disturbed and denuded group will rest upon it unconformably.

1416. Faults; Dykes.—Intrusive rocks may occur in the form of veins, traversing at any angle the rocks among which they rise, in the form of wall-like masses or dykes, or as irregularly circular masses forming the upper ends of vertical columns or pipes called "necks." Dykes vary from less than an inch in thickness to over 70 feet, and often carry iron which attracts the magnetic needle to such an extent that the dykes can frequently be traced long distances by that means.

Fig. 398 shows several faults, but they are all from the same parent bed. Unless very carefully examined, a minor fault or secondary slip or dislocation may be mistaken for an important and dominant fault, the evidence of which might be elsewhere obtainable, but which might never be seen itself. An exposure of a fracture will give the exact position of the line of fault at that place, but it is not necessary to prove the existence of either the minor or dominant fault, nor will the exposure furnish additional information of any value or importance. As a rule the large faults which powerfully affect and influence geological structures are seldom found in any visible form. In this way three another. This class of section requires good exposures and careful measurement.

The construction of the horizontal section is different. It may be necessary to construct a section of a district where exposures are few, where minute measurements are impossible, and where the best skill of the prospector is required to unravel the meaning of the facts noted upon the surface, and show their bearing on the rocks below ground. A section of this kind should be constructed so that the heights and lengths are on the same scale, if possible. When the ground is comparatively level, to use a scale large enough to show the elevations and depressions would make the section exceedingly long on paper. In such a case it would be best to use a larger scale for the vertical heights than for the horizontal distances, but exaggerating the height of the section should be avoided as much as possible.

Sections are generally drawn at right angles to the strike, but in special cases, to make clear certain formations, they may be drawn at any angle from the strike.

1422. Section and Curvature of Strata.—Having obtained the elevations of the points on the surface through which the section runs, the next step is to lay off on a base line, or datum, measurements to scale, showing the horizontal distances between the points. From these points on the datum perpendicular lines must be drawn, and the height of each point marked by scale on its perpendicular, as in skeleton section of Fig. 400. A line is then drawn connecting all the points. This gives the general contour of the ground. More details can be secured by taking the skeleton section in hand and walking over the ground, filling in all little inequalities of surface. This may also result in securing more evidence as to the nature and structure of the rocks. Some of the data for such a section may be secured in places at some little distance from the actual line of the section. The skeleton section (Fig. 400) shows what is exposed to the view, while the complete section is constructed from these exposures and the logical inferences that

TABLE 29.

OBLIQUE SECTIONS.

$b =$		5°	10°	15°	20°	25°	30°	35°	40°	45°	50°	55°	60°
		Corrected Angles.											
$c =$ 5°	$a =$	4° 59′	9° 58′	14° 57′	19° 56′	24° 55′	29° 50′	34° 54′	39° 51′	44° 53′	49° 54′	54° 54′	59° 54′
$c =$ 10°		4° 55′	9° 51′	14° 47′	19° 43′	24° 40′	29° 37′	34° 35′	39° 34′	44° 34′	49° 34′	54° 35′	59° 37′
$c =$ 15°		4° 50′	9° 40′	14° 31′	19° 22′	24° 15′	29° 09′	34° 04′	39° 02′	44° 00′	49° 01′	54° 04′	59° 08′
$c =$ 20°		4° 42′	9° 25′	14° 08′	18° 53′	23° 40′	28° 29′	33° 21′	38° 15′	43° 13′	48° 14′	53° 18′	58° 26′
$c =$ 25°		4° 32′	9° 05′	13° 39′	18° 15′	22° 54′	27° 37′	32° 24′	37° 15′	42° 11′	47° 12′	52° 19′	57° 04′
$c =$ 30°		4° 20′	8° 41′	13° 04′	17° 30′	22° 00′	26° 34′	31° 14′	36° 00′	40° 54′	45° 54′	51° 03′	56° 18′
$c =$ 35°		4° 06′	8° 13′	12° 23′	16° 36′	20° 54′	25° 19′	29° 50′	34° 30′	39° 19′	44° 56′	50° 20′	54° 49′
$c =$ 40°		3° 50′	7° 42′	11° 36′	15° 35′	19° 39′	23° 51′	28° 16′	32° 44′	37° 27′	42° 25′	47° 34′	53° 00′
$c =$ 45°		3° 32′	7° 06′	10° 44′	14° 26′	18° 15′	22° 12′	26° 21′	30° 41′	35° 16′	40° 07′	45° 17′	50° 46′
$c =$ 50°		3° 13′	6° 28′	9° 47′	13° 10′	17° 28′	20° 22′	24° 14′	28° 20′	32° 44′	37° 27′	42° 33′	48° 05′
$c =$ 55°		2° 52′	5° 46′	8° 44′	11° 47′	14° 58′	18° 19′	21° 53′	25° 42′	29° 50′	34° 21′	39° 19′	44° 59′
$c =$ 60°		2° 30′	5° 02′	7° 38′	10° 19′	13° 07′	16° 06′	19° 17′	22° 45′	26° 34′	30° 27′	35° 32′	40° 54′

may be made. Along the limited exposures of strata usually visible, the planes of dip often seem to be straight lines. Bed succeeds bed, inclined, and forming a succession of parallel bands. But if the section could be continued downwards beneath the surface, or the rocks exposed on the bare steep side of a great mountain, it would be observed that though, when examined within the limited area of a few yards, the beds look as if they sloped in straight, stiff lines, in reality they are portions of great curves, as shown by dotted lines in Fig. 400.

An exact method, however, of determining the underground curves from surface dips can not be devised, and in the absence of exploratory bore holes, the depth and curvature of a coal or other mineral bed can be indicated only approximately, and by very imperfect methods.

1423. Oblique Section.—In order to draw an oblique section, such as a section through line $C D$ in Fig. 399, the necessary correction of the true dip must be made by means of the following formula:

a = tangent of angle of corrected dip;

b = angle of dip at right angles to strike;

c = angle at which the section lies to right, or left, of the full dip.

$$a = \tan b \times \cos c. \qquad \textbf{(84.)}$$

EXAMPLE.—Angle of dip is 45°, and the oblique section line runs at an angle of 30° from the true dip; what will be the dip on line of oblique section?

SOLUTION.—Tan of 45°, or 1.0000, × cos of 30°, or 0.866 = 0.866 = tangent of 40° 54'. Ans.

The accompanying table of Oblique Sections, calculated from the above formula, gives the correction for the most useful angles.

1424. Boring and Trial Shafts.—By referring to Fig. 403 (which is a section showing anticlinal and extension of coal field, entirely concealed by new formations, only discoverable by boring), it will be seen that surface exposures, although of great value to the prospector because they lead up to logical conclusions, are not all-sufficient Under such circumstances as indicated on the right of Fig.

FIG. 403.

403, and many other conditions, recourse must be had to trial shafts and boring in order to get the necessary data to complete the map, so that it will be in shape to indicate conclusively at which point the openings may be most advantageously and economically located.

A shaft will show the ground more plainly than a bore hole, but the cost of sinking beyond shallow depths bars it out. A prospect shaft seldom exceeds 200 feet, and cases where it reaches this depth are exceedingly rare. Apart from the consideration of cost, the consideration of time is all important. Prospecting by drilling is more rapid. When the property, however, has been drilled and otherwise thoroughly investigated, a trial shaft should, when practical, be sunk to prove the quality of the coal, the nature of the roof and bottom, etc. Boring, while proving the *existence* of coal, can not give an adequate knowledge of its commercial value. This can be secured only by driving into the seam sufficiently far from the surface to get a good average sample of the coal.

Some seams are so largely made up of bony çoal and other inferiorities that in appearance are like good coal that boring does not always afford reliable data, and when the shaft is sunk to develop the coal it turns out unsalable.

The experience of the past few years in coking Appalachian coals affords assurance that their coking properties can be estimated with a good degree of confidence by the ratio of volatile hydro-carbons to the fixed carbon. Nevertheless, it is only by practical tests that any coal can be properly judged as to its coking properties, and the value of the coke for metallurgical and other uses.

Thick seams, reported as having been proved by boring, sometimes turn out on investigation to be largely made up of more or less thick layers of worthless materials interstratified with good coal.

A drill furnishing a core is less liable to deceive in this respect than those which furnish only ground samples fished out by a sludger, cleanser, or sand pump.

Coal seams are sometimes practically valueless, owing to the roof being so rotten or dangerous, and so expensive to maintain or carry, that the coal can not be profitable mined.

In some cases it may happen that the overlying strata contain so much water, or are so loose and sandy, that mining operations beneath are quite impracticable. A better idea of these conditions is obtained by sinking a trial shaft or drift and driving a heading or two into the seam.

The strata of some districts contain so much water that it is necessary to have the first shaft sunk large enough to facilitate putting in large pumping fixtures. In such a case the prospect shaft should be carefully located and of such size that, should the coal be workable, it may be used as one of the principal openings in the future development.

1425. The two chief methods of boring are:

1. By percussion drill, which chips the rock into small fragments, subsequently removed.

2. By a rapidly revolving ring, which grinds the rock in an annular space into dust.

The machines classed under the above headings will be described later.

1426. Systematic Record of Details.—The systematic recording of all details in a prospect is the most important part of the whole proceedings. Cases are on record where a district was prospected by boring, twice

A, *B*, and *C*. By drawing the lines from *A* on the north river to *A* on the south, the probable outcrop of that seam is shown. The same will be true of the other two seams.

This outcrop may be verified by the following method: From the point *D* on the outcrop line *A A*, draw a line *D F* on the map at right angles to the line *A A*. Supposing the surface to be level from *D* to *F*, measure off a distance, say 100 yards, from *D* to *E*. As the angle of dip of the seam *A A* was indicated by the clinometer, the depth at which the seam *A A* lies below *E* can be calculated by a similar method. The distance from the probable line of outcrop of *B B* to *E* may be calculated, and also the angle of dip of *B B* being known, the depth at which *B B* underlies *E* may be calculated.

Supposing the angle of dip of each seam is 40°. If the distance from *D* to *E* is 100 yards, or 300 feet, then having the horizontal distance *D E*, as measured on the level surface of the ground, and the angle 40°, by multiplying the distance *D E* by the natural tangent of the angle, the required depth is found.

In this case the distance is 300 feet. The natural tangent of 40° is .8391; therefore, $.8391 \times 300' = 251.73$ feet deep, from the surface at *E* to seam *A A* vertically below point *E*.

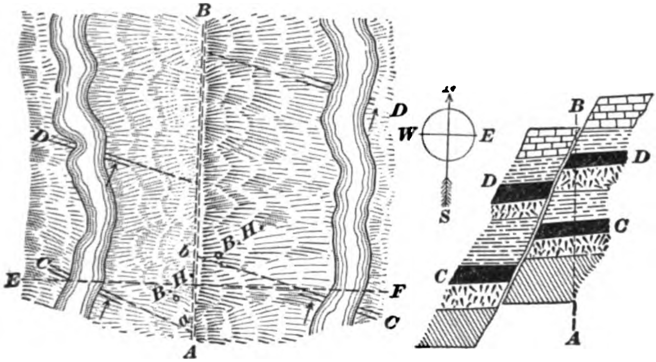
In the same manner, if the distance from the probable line of outcrop of coal *B B* is 150 feet to *E*, then $.8391 \times 150$ feet $= 125.86$ feet deep from surface at *E* to seam *B B* vertically below point *E*.

The same results can be obtained by the rule given in Art. **1387**, if it is remembered that one angle of a right-angled triangle is always 90°, and the third angle can be found by subtracting the given angle + 90° from 180°.

By putting down another hole at *F* and calculating the depths in the same way, it will be known at what depth to expect all the seams *A A*, *B B*, and *C C* at *F*.

Care must be taken in setting out the line *D E F* at right angles to the line of outcrop, or otherwise the true angle of dip will not be obtained.

indicated crop lines not lead to the seam on the other river, is a natural question. There must either be a swelling of the strata between the outcrops or there is a fault of vari-



Plan.

Section at right angles to line $A\ B$ through the line $E\ F$.

FIG. 407.

able throw between the two rivers. To prove which of the two assumptions is correct, a number of trial shafts or shallow bore holes must be put down, as the rules previously given can not be successfully applied.

1432. Trial Shafts.—Good laborers will sometimes sink a shaft ten feet deep without a staging, that is, a platform to throw the dirt on.

When the depth exceeds ten feet, it is necessary to build a staging or cut a step to throw the earth upon (from which it is again shoveled and thrown from the pit), or to erect a windlass for hoisting.

When the depth exceeds fifteen or eighteen feet a windlass becomes necessary. This may be a very primitive affair, but should be strongly built. A hemp rope one inch in diameter and a strong iron-bound wooden bucket holding about 80 or 100 pounds complete the outfit.

The upright upon which the rope shaft rests should be securely braced both at the sides and back.

Some men prefer sinking square shafts, others prefer sinking round holes. If the ground is firm, the shape is a matter of minor consideration. A rectangular hole about sometimes tend to deceive the prospector. For instance, suppose two bore holes are put down at *A* and *B* (Fig. 408), say 3,000 feet apart. The bore hole at *A* proves a seam 3

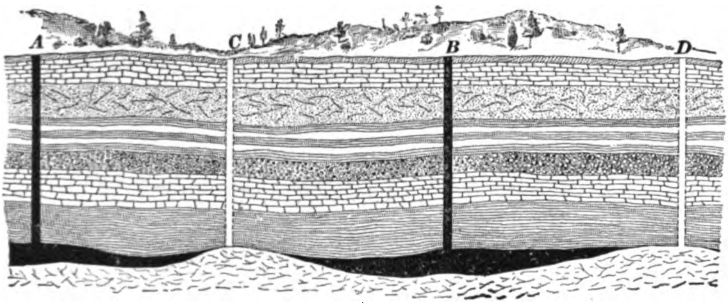


FIG. 408.

feet thick, and at *B* the coal is found at about the same level 6 feet thick. It would be natural to suppose that this seam was one which was gradually thickening as it went from *A* towards *B*, and that it would be found about four feet thick at *C*, or seven to eight feet thick at *D*; whereas, it is only a streak, or there is no trace at all at these points. These pockets of coal are frequent, and very deceptive to the inexperienced.

Again, if bore holes were put down at *C* and *D*, finding no coal but Sub-Carboniferous strata instead, that does not absolutely prove there is no coal, for a hole at *A* or *B* would find coal. These are samples of conditions that are frequently met in some of the American coal fields.

1434. The splitting of coal beds is a very common occurrence, and this should always be watched for in boring. It is not sufficient simply to bore down to the bottom of a seam whose existence is to be proved. For instance, in Fig. 409 bore holes have been put down at *A* and *B*. Each of these proves a seam of coal at about the same depth and of the same thickness. If the bore hole *B* had been deepened it would have shown quite different results.

As some coal beds are so much cut up and disturbed by "clay veins," "horses," etc., as to become unworkable at a profit, it is necessary for the prospector to scan the outcrops for them, and in boring to anticipate them and make all due allowances.

It should be remembered that sandstones are apt to vary

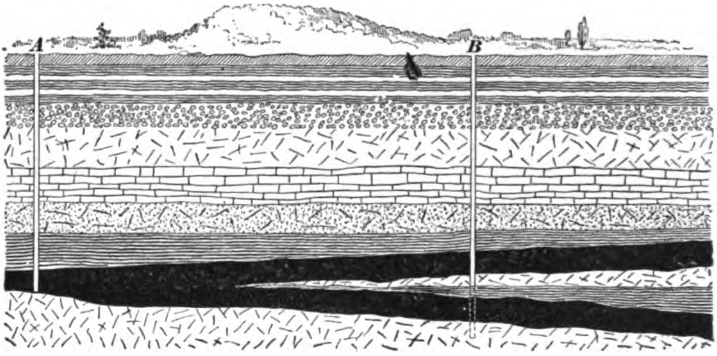


FIG. 409.

in thickness and persistency more than the other varieties of rock in the coal measures; therefore, they do not afford such reliable evidence of the near existence of coal seams as strata of other kinds of rock.

Wherever organic matter is found, whether in the form of fossils or coal, the sandstones and shales are white or gray. All sandstones of the Carboniferous measures, or of other strata, containing coal are gray, while the old red sandstone below the coal and the new red sandstones above the coal, and, in fact, all red sandstones, are very poor in fossils or evidence of organic matter of any kind.

1435. Before leaving this subject, one more instance, embracing both conditions, will be given.

The imaginary line about which the beds may be supposed to be bent is called the axis of the anticline or the syncline. This axis may be either horizontal or inclined. If it is horizontal, sections taken in any part will show the same beds. But if it is inclined, different sections will cut different beds. Prof. Jukes, of the British Geological Survey, gives the example shown in Figs. 410, 411, and 412. Fig. 410 is a plan of undulating beds, the axis of the anticlinal and synclinal curves being inclined—in this case

case of the anticline, or resting upon each other in the case of a syncline. Thus, bed No. *4* will "nose in" under the new bed No. *5*, which, in its turn, will "nose in" under No. *6*, and so on. In like manner, in the syncline, bed No. *14* will "nose out" over No. *13*, No. *15* over No. *14*, and so on. Hence, if a section is taken along the line *C D* in the plan (Fig. 410), such a section will appear as in Fig. 412, in which bed No. *4* forms the crest of the anticline, and bed No. *13* is the highest in the syncline. But if a section be taken along the line *G H*, this section will appear as in Fig. 411, in which bed No. *7* forms the crest of the anticline, and bed No. *16* is the highest in the syncline. It is of the utmost importance to observe carefully the inclination of the anticlinal and synclinal axes.

1436. Sir Charles Lyell has probably presented this matter clearer than ever before:

"There are endless variations in the figures described by the basset-edges (outcrops), according to the different inclinations of the beds, and the mode in which they happen to have been denuded.

"One of the simplest rules with which every prospector should be familiar relates to the **V**-like form of the beds as they crop out in an ordinary valley. First, if the strata be horizontal the **V**-like form will be also on a level, and the newest strata will appear at the greatest height.

"Second, if the beds be inclined and intersected by a valley sloping in the same direction, and the dip of the bed be less steep than the slope of the valley, then the **V**'s, as they are often termed by miners, will point upwards (see Fig. 413), those formed by the newer beds appearing in a superior position and extending highest up the valley, as *A* is seen above *B*.

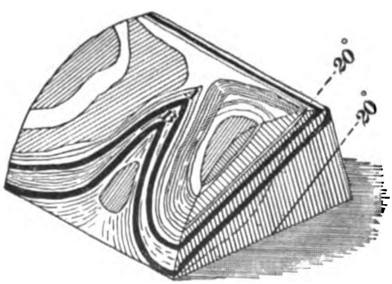


FIG. 413.

"Third, if the dip of the beds be steeper than the slope crucible should be placed on a firebrick resting on the grate bars supporting the glowing coals. Shake coals around it until only the top of the crucible protrudes.

When the mass, which at first swells up, is fused, cover the crucible entirely with coals, and increase the heat for ten minutes to collect the lead in a button and then take it out. The whole operation lasts from 45 to 60 minutes. Break up the crucible, clean the button from adhering lead oxide by means of a brush, and weigh. To obtain a reliable average, from two to four tests must be made. As unity we refer to carbon, which reduces 34 times its weight of lead. The calorific power of carbon is 8,086 French heat-units*; every part of lead produced in the button $= \frac{8,086}{34} =$ 238 heat units. This result multiplied by the weight of the lead button, in grammes, gives the heat units contained in the coal. This result is not absolutely correct, but at most is only one-tenth too low, and is closer the higher the percentage of carbon in the coal.

It must be borne in mind that the result is the amount of heat, not the intensity, as that depends on the rate of combustion.

1442. Coking Coal.—As was stated before, the only positive manner of testing a coal for coking properties is a practical test ; but among some coals of the eastern side of the Appalachian field there is a ratio between the hydrocarbons and fixed carbon, which enables a fair conclusion to be drawn as to their coking qualities. The coals of the western side contain too much bituminous matter to make very good coke. For this reason, but a small amount of coke is made in the pitchy coal fields of Ohio, Indiana, and Illinois.

The Colorado, Wyoming, Montana, New Mexico, and other Western, or Northwestern and Southwestern, coals belong to the Trio-Jurassic and Laramie-Cretaceous

* A French unit of heat is equal to 3.96832 British thermal units, or, in other words, one French unit of heat will raise the temperature of 1 kilogramme of water 1.8° Fahr.

weight of a bulk of water equal to the bulk of the body. Diff. of weights: Weight in air :: 1 : x, or

$$\frac{\text{Weight in air}}{\text{Difference}} = \text{specific gravity of body.}$$

EXAMPLE.—A piece of coal weighs 480 grains in the air and weighs 398 grains less in water. What is the specific gravity?

SOLUTION.—$\frac{480 \text{ grains}}{398 \text{ grains}} = 1.206$ specific gravity. Ans.

1444. Weight of Coal.—A cubic foot of water weighs 62.355 lb., and this 62.355 lb., multiplied by the specific gravity of coal, gives its weight per cubic foot. Thus, 62.355 × 1.206 = 75.2 lb. per cu. foot, when the specific gravity of coal is 1.206.

1445. Tonnage per Acre.—The number of tons of coal in any tract of land may be calculated by finding the number of cubic feet and multiplying it by the weight of a cubic foot in lb., and dividing the product by 2,240 for long tons, and 2,000 for short tons.

EXAMPLE.—How many tons are in an acre if the coal is 20 inches thick and the specific gravity is 1.206?

SOLUTION.—One acre = 43,560 sq. ft.

20" thick = $1\frac{8}{12}$ or $1\frac{2}{3}$ feet.

43,560 × $1\frac{2}{3}$ = 72,600 cu. ft.

As was stated above, coal having a specific gravity of 1.206 weighs 75.2 lb. per cu. ft.; therefore, 72,600 × 75.2 lb. = 5,459,520 lb., and $\frac{5,459,520 \text{ lb.}}{2,000 \text{ lb.}} = 2,729.8$ short tons per acre. Ans.

A very convenient manner of making such a calculation is that used by Scotch mining engineers when checking the reported tonnage of the operator to the proprietor of the estate.

The specific gravity is found, the decimal point is removed, and the figure 1 is annexed; this gives the tonnage per inch per acre with due allowance for faults, wants, etc.

EXAMPLE.—How many tons of coal are in an acre, the coal being 3 feet thick and specific gravity 1.3?

SOLUTION.—Specific gravity being 1.3, the number of tons per inch per acre will be 131.

131 tons × 3 (feet) × 12 (inches) = 4,716 tons per acre. Ans.

precaution in some seams the main hauling roads can be maintained only to a limited extent, and to reach the coal beyond this limit no other course is open but to sink shafts close enough together to each other so that the limit of the entries or gangways from each shaft or drift will meet, ensuring, as nearly as possible, the extraction of all the coal.

1450. When the dip of the valley in which the coal crops out is equal to or greater than the dip of the coal and in the same direction, as a matter of course, if the railway or even a tramway can be readily built to the opening it should be made at the lowest point of the area it is to supply the outlet for, to ensure a favorable mule haulage and good self-drainage. In some districts the coal is so undulating and irregular that drainage and haulage have no weight in deciding upon the position of the location. The object

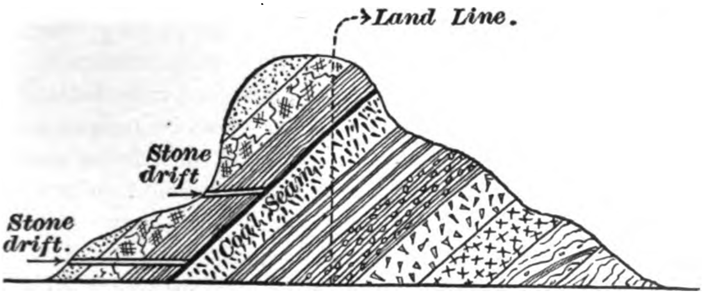


FIG. 420.

here to be considered is a suitable site for hauling and pumping machinery. When the seam has a heavy pitch inwards and the hills are high, a "day drift" or level may be located in a ravine or gulch eroded across the strike (see Fig. 420), and the coal can be reached by a short "tunnel" or "stone drift," from which the coal lying above it can be mined. If the length above the drift is less than 200 feet to 300 feet, a slope had better be started at once.

1451. When the seam has considerable dip and is brought close to the surface by an anticlinal axis, a "rock slope" dipping at the same angle as the seam may be started both to the area of the field and the area for which each shaft will be the outlet. In order to accomplish this it will be best to wait until the extent to which the workings of the first shaft can be profitably extended, mechanical haulage considered, is determined. The demand for a very large tonnage early in the history of the field sometimes requires more than one shaft at once, in which case the best location must be selected that is indicated by the information on the map.

Quicksands may modify the arrangements, as may also great quantities of water, but never to any great extent in these days of improved facilities for sinking.

Slopes, up to the present time, have been and still are greatly preferred to shaft openings at all points in the anthracite regions of Pennsylvania, where the coal is accessible along its outcrop and where the dip is more than 15° or 20°.

In the bituminous region of Pennsylvania and many of the Western States shafts of moderate depth are common.

As many outcropping seams have a slight inward dip, to ensure a long level haulage road and good water drainage, the opening is commenced several feet below the terrace, and driven level, or on a very slight up grade, until the normal dip is reached. It sometimes happens that the inward dip is so strong that it is advisable to open by a shaft sunk in the center of the basin, provided the depth is not too great and the amount of water small. When the inward dip to the center of the basin does not exceed about 24′ or 26′, drainage may be accomplished through a drift, by siphon, the pipes being of the diameter required to remove the water.

the loaded cars would have the advantage of the down grade, and there would be no need to sink a shaft to win the coal.

1454. In the case of a seam of coal lying at a considerable dip, and having its outcrop on the side of a hill, as at *a* in Fig. 422, the seam can be opened out in three different ways: 1. A slope can be driven in the seam from *a* to *b*, and the coal drawn and water pumped up the slope. This system would have the advantage of enabling the coal field to be more rapidly opened out by means of levels, gangways, or benches turned off at intervals to the right and left of the slope as it is being driven down towards *b*. 2. The coal can be won by a shaft sunk to *b* from the surface at *c*. 3. A tunnel can be driven to *b* from a point *d* on the hillside. This tunnel will have the advantage of a dip towards *d* whereby the entire coal field can be drained by gravitation without any expense for pumping machinery. The haulage can also be done cheaply for the same reason. The decision as to whether the shaft *c b* or the tunnel *d b* will be preferable depends on at least two conditions. If the seam lies somewhat flat, a shaft will be preferable, because a shallow shaft will reach the greater area of coal; but if the seam is more than 45° from the horizontal, then a tunnel will be preferable.

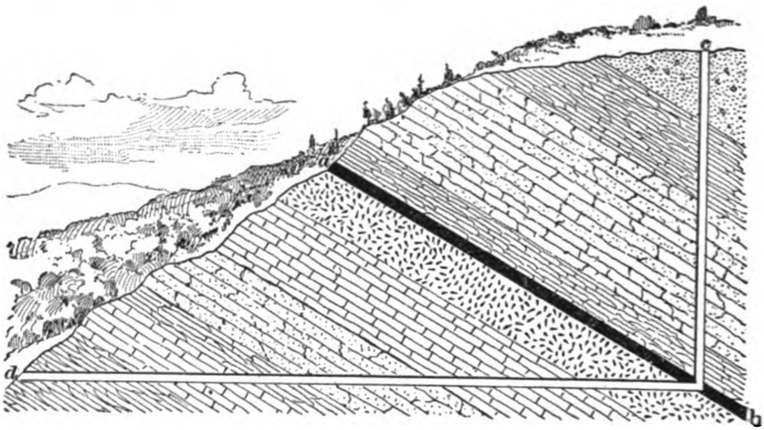


FIG. 422

The speed of hoisting the output may vary from 24,000 feet per hour to 40,000 feet, or more, per hour, including the time taken up in charging and discharging at top and bottom.

By deciding upon the required tonnage, the probable depth of the shaft to reach the seam, and the desired output speed, the following rule may be used to find the length of the winding compartments:

Let S = output speed;
D = depth of shaft;
T = tonnage expressed in pounds;
N = number of working hours;
W = weight of a cubic foot of broken coal;
B = average inside width of car;
d = inside depth of car;
L = length of compartment;
f = clearance in shaft at ends of cage = 1 foot.

Then, $$L = \frac{T D}{S N W B d} + f, \qquad (85.)$$

that is, the length of the compartment equals the tonnage in pounds times the depth of the shaft divided by the continued product of the output speed in feet per hour, the number of working hours, the weight of the coal per cubic foot, the width of the car, and the depth of the car plus the clearance.

EXAMPLE.—Tonnage, 960; number of working hours, 10; depth of shaft, 500 feet; weight of a cubic foot of broken bituminous coal, 50 lb.; output speed, 30,000 feet per hour; average inside width of car, 4 feet; inside depth of car, 3 feet. What is the length of the compartment?

SOLUTION.—

$$L = \frac{960 \times 2{,}000 \times 500}{30{,}000 \times 10 \times 50 \times 4 \times 3} + 1 = 6 \text{ feet 4 inches in the clear. Ans.}$$

1460. The width of the compartment is yet to be determined. The average width of the car may be 4 feet, but it may be flared to 5 feet at the top, so that the cage will have to be 5 feet plus the clearance on each side of the car—say 3 inches on each side—making it 5 feet 6 inches.

Add to this the width of the angle iron and shoe used in constructing the cage—say 6 inches on each side—making 5 feet 6 inches + 1 foot = 6 feet 6 inches. The conductors, or guides, if of wood, may be from 4 to 6 inches thick—in this case say 4 inches each, and there are two of them—making 6 feet 6 inches + 8 inches = 7 feet 2 inches as the width of the compartment in the clear. In calculating the total length of the shaft, if there are two hoisting compartments and a pumpway, twice the width of the hoisting compartment in the clear plus the width of the two buntons plus the width of the pumping compartment in the clear, equals the total length of the shaft in the clear.

Thus,

$$\begin{pmatrix}\text{compartments}\\ 7'\,2''\times 2\end{pmatrix}+\begin{pmatrix}\text{two buntons}\\ 1'\,4''\end{pmatrix}+\begin{pmatrix}\text{pumpway}\\ 6'\,0''\end{pmatrix}=21'\,8''.$$

The shaft will, therefore, be 21 feet 8 inches by 6 feet 4 inches in the clear.

This calculation may be modified in various ways. For instance, the tonnage may be nearly doubled under exactly the existing conditions if a double-deck cage is used; or, with the same speed and length of cage, the tonnage be doubled by lengthening the shaft so that two cars can stand side by side on each cage; or the length of the cage may be such that two cars can stand tandem; or these various conditions may be combined on a single-deck cage, and four times the original tonnage hoisted at the same speed. The tonnage may be increased, without enlarging the cage, by increasing the output speed. These statements do not take into consideration the power of the engine, which will have to be strong enough to start the load and hoist it at a sufficient speed.

1461. When the size of the shaft has been determined, the next thing in order is to consider the position of the sides of the shaft in relation to the dip of the seam. The long side of the shaft should be as nearly as possible parallel with the line of the dip. When the ends of a cage are in line with the strike of the seam, the charging of the cages from the shaft. In case anything happens to the inner stakes the outer ones can be used to reset them. The outer stakes should be driven below the surface and their approximate location marked with a stake or stone so they can easily be found. Sometimes surface conditions exist which make it desirable to wall the upper part of the shaft with stone. In such a case the outside cribbing consists of timbers, shown at *a*, *a*, Fig. 424, and lining plant *b*, *b*. The timbers *a*, *a* may be

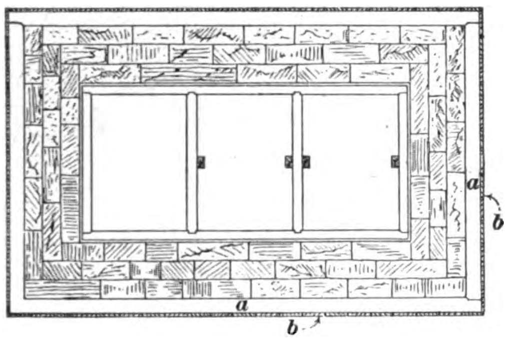


FIG. 424.

12″ × 12″. Each set is placed from one foot to four feet, or more, apart, according to the looseness of the ground sunk through, and held in position by punch blocks *B*, Fig. 425.

1464. The sinking should be carried far enough into the stratum, or "hard pan," to ensure a solid foundation for the stone wall. If there is much water, the outside timbering should be removed as the wall is built up, and its place filled with clay, well rammed, to keep back the water. This part of the shaft is then completed, the buntons being put in as the walling is carried upwards. If it is desirable to carry the regular timbering clear to the surface, instead of building the buntons into the walling, the walling must set back far enough for the regular timbering to be put in.

1465. Figs. 424 and 425 show the walling and timbering of a rectangular shaft. It is necessary to timber only where the material sunk through will not stand, or where it is necessary to dam back feeders of water.

A set of timbers for a shaft of three compartments usually consists of :

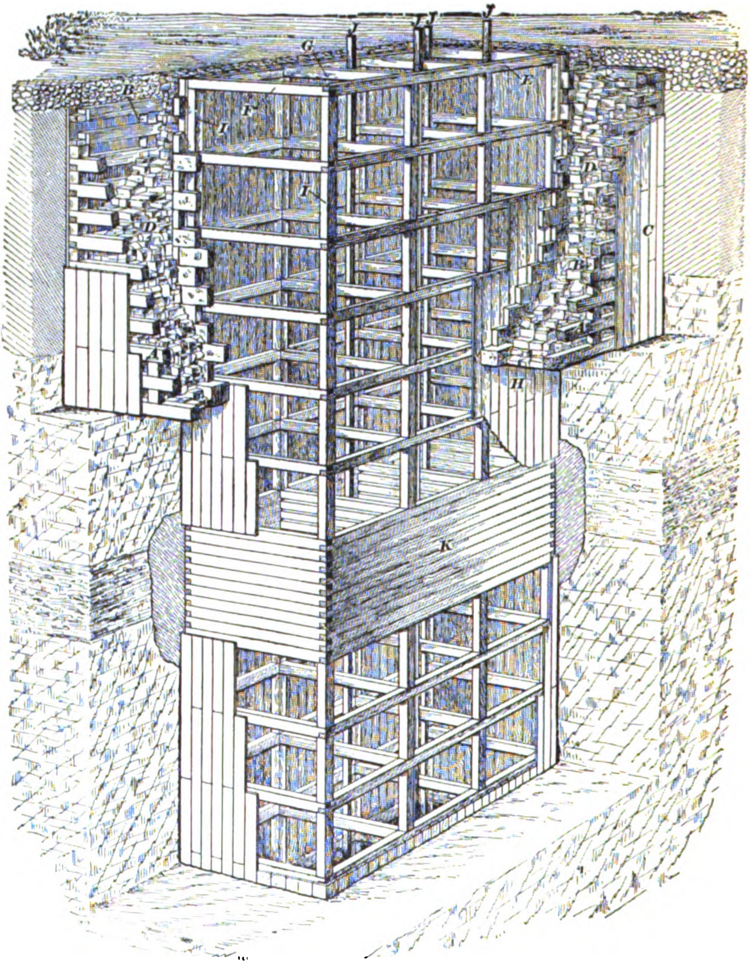


FIG. 425.

1. 2 side pieces, 10″ × 10″ × — feet.
2. 2 end-pieces, 10″ × 10″ × — feet.
3. 2 buntons, 10″ × 10″ × — feet.
4. Sufficient 2 or 3 inch plank to go around the shaft for

1468. If, after the shaft has penetrated the hard strata for some distance, a slight feeder of water is met which can not very well be dammed back, or the water-bearing stratum is very thick and the water only percolates through it into the shaft, the cost of a cofferdam prohibits its use. A "water ring" is then made by widening the shaft at *a*, Fig. 426, and again contracting it at *b*.

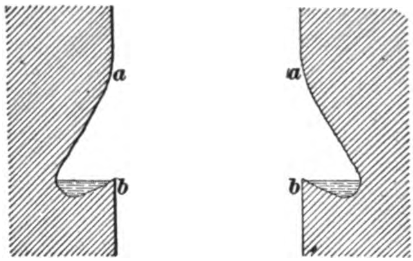


FIG. 426.

The water may be conducted from this "water ring" in pipes to a sump at the shaft bottom.

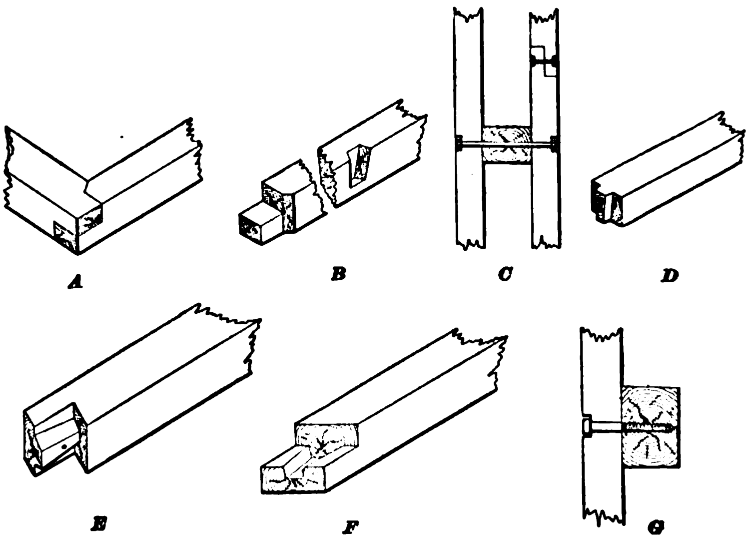


FIG. 427.

1469. Fig. 427 illustrates all the joints used in fitting the shaft timbers together.

A shows the joint of end and side timbers.

B shows the side timber joint and also the dovetailed mortise to receive the dovetailed tenon of bunton *D*.

D shows the dovetailed tenon to fit in dovetailed mortise shown in *B*.

E and *F* show the method of jointing the guides, or conductors.

C shows the manner of bolting *E* and *F* together, and also shows how guides, or conductors, are bolted to the buntons.

G shows the guide fastened to the side with a large screw, countersunk, as it is impossible to get behind the timbers when putting in the guides to screw up a nut on a bolt.

There are many other forms of joints, but those given are the best known, and should be used.

1470. A plan of the shaft mouth showing carriage

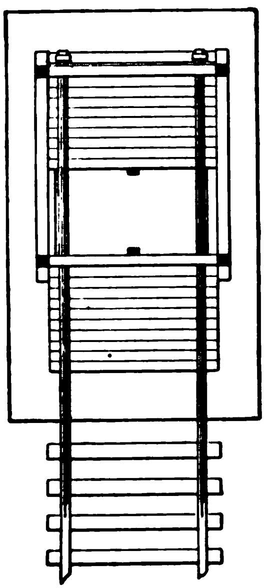


FIG. 428.

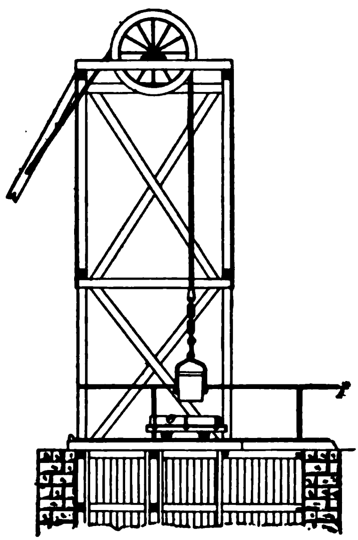


FIG. 429.

track and derrick is given in Fig. 428. In Fig. 429 the is permanently fastened to the rope by the wrought-iron bow *s* is now lowered, emptied into this car, and again raised into position ready for lowering into the shaft. The car is now run back from the mouth of the shaft, and the rock, etc., unloaded.

The wrought-iron bow *b* (Fig. 430) of the bucket is attached to it at a point below the center of gravity, so that when full the tendency is for the bucket to turn over and empty itself. To prevent this while hoisting, a short vertical pin *g* is riveted to the side of the bucket, and an ordinary chain link sliding on one arm of the bow passes over it.

1472. Covering the mouth of the shaft with a traveling car while sinking is open to a great number of objections, to overcome which the arrangement of levers and counterbalances shown in Fig. 431 may be used.

Each door is bolted to two hinges *d*, *d*, which are keyed

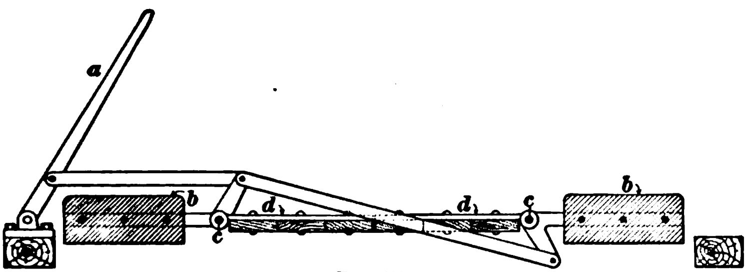


FIG. 431.

on shafts *c*, *c*. By means of the handle *a*, and the connecting arms, a rotary movement is given and the doors lift as the lever is pulled back. The weight of the doors is counterbalanced by four blocks *b*, *b*, so that they will stand at any position desired.

1473. Sinking Guides.—The oscillation of the bucket in deep sinking becomes very great, and much time is lost in steadying the bucket before it starts upwards. The best method to overcome this is shown in Fig. 430. The guide ropes *c*, *c* are coiled on a drum at the surface so that they can be lengthened as the sinking advances. These ropes the back of the plate and the side of the strata to prevent any movement of the segments.

When a number of courses of tubbing have been set up in place, all joints are wedged up; that is, small wedges of red pine are inserted in the sheathing and driven in until the wood becomes compressed so hard that the chisel edge can not be driven into it.

The tubbing is put up in lifts or sections. A lift or section at Sydney mines consisted of a wedging curb and from five to fifty courses of tubbing built thereon.

1480. The following formula is used for calculating the proper thickness for cast-iron tubbing:

Let t = thickness of tubbing in inches;
d = diameter of shaft in feet;
D = depth in feet;
G = the crushing load of cast iron per square inch; usually taken at 90,000 pounds.

$$t = \frac{6\,d\sqrt{G} - 6\,d\sqrt{G - 6.944\,D}}{\sqrt{G - 6.944\,D}} \qquad \textbf{(86.)}$$

$$= \frac{1{,}800\,d - 6\,d\sqrt{90{,}000 - 6.944\,D}}{\sqrt{90{,}000 - 6.944\,D}}, \text{ when } G = 90{,}000.$$

The upper course of tubbing should in all cases be at least ½ of an inch thick in the plate, even in shafts of very small diameter; and ⅝ of an inch thick in shafts of large diameter, to prevent liability to fracture. It is also desirable to add a constant, usually ¼ of an inch, to the thickness obtained by the formula, to allow for wear and tear, and for corrosion or other chemical action on the metal.

In this formula, no allowance is made for the extra strength given the segments by the flanges and ribs. Theoretically, each set of segments should have a different thickness, but in practice they are calculated for every 25 or 30 feet.

SOLUTION.—By substituting these values in the preceding formula, we have

$$t = \frac{1,800 \times 13 - 6 \times 13\sqrt{90,000 - 6.944 \times 800}}{\sqrt{90,000 - 6.944 \times 800}}$$

$$= \frac{23,400 - 6 \times 13 \times 290.6}{290.6} = \frac{23,400 - 22,666.8}{290.6} = 2.523 \text{ in.}$$

Now, adding $\frac{1}{8}$ in. for wear and tear, we obtain thickness = 2.523 + .125 = 2.648 in. Ans.

1481. Fig. 433 shows the timber lining, brick walling, and tubbing employed in circular shafts, each, of course, being applied under different conditions.

L shows the timbers laid across the top of the shaft, *M* the timbering curve, *N* the punch blocks, *O P* the backing plank, *R* the stringing board, *S* the walling curb with the walling upon it, and *T* the hollow cast-iron wedging curb with cast-iron tubbing resting upon it.

1482. Water Rings. — Scarcely any strata which require walling will be perfectly dry, consequently water will percolate through the brick. It is caught in water rings, garlands, curb rings, ring curbs, or ring gibs that are put in, and from which the water is conducted to the sump through a line of pipes.

Figs. 434, 435, and 436 show the details of construction of several styles of water rings. In each figure, *a* is the crib, in which a gutter is usually hollowed out to catch the water, *b* is the walling both above and below the crib, and *c* is the waste pipe which conducts the water down the shaft from the gutter *d*.

1483. Brick, Stone, and Wood Walling.—When the shaft has been sunk deep enough for a walling staging, the seat for the segmental wedging curb is cut and the sinking carried down 5 or 6 feet, more or less as the case may require, below the curb, at the same diameter as the internal is filled with compressed moss *m*. Wedges *w* are then placed between this 2-inch strip of wood and the curb, and tightly driven in, thereby compressing the moss still more.

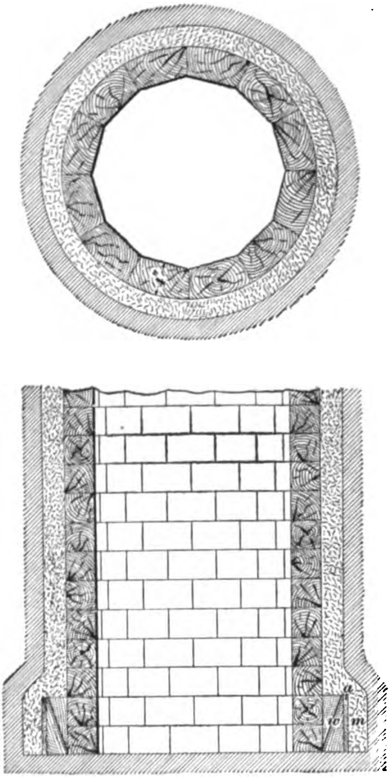


Fig. 438.

1485. Supporting Curbs.—Sometimes, in passing through broken strata, it is necessary to put in a supporting curb. There are several ways of doing this, but perhaps as good a way as any is to drill holes into the wall about 2 feet apart, taking great care to have them in a horizontal plane. Then the curb will be level when resting on bars of iron or steel, 2 or 3 inches in diameter, inserted in these holes. See *b*, Fig. 437.

1486. Bricks.—The dimensions of bricks for shaft lining vary, many engineers preferring under all conditions the ordinary rectangular brick. Some prefer the ends, and others the sides, curved to correspond with the inner and outer circumference of the shaft lining, while still others prefer to have the bricks molded into a form to suit the special case.

Good hard-burned rectangular brick, free from clinkers and pebbles, with a fairly rough face which ensures that they have not been over-burned, are the best.

Some engineers prefer to have all brick laid with the long side in line with the shaft diameter, while others prefer the brick laid with the long side running with the circumference, every fourth or fifth course being laid contrariwise, as binders.

1487. There is no definite rule for determining the number of bricks required for shaft lining, on account of chipping and mortar, but an approximation may be made by the use of the following formula:

Let N = number of bricks required;
D = outer diameter of the shaft;
d = inner diameter of the shaft;
t = thickness of brick;
b = breadth of brick;
l = length of brick;
x = depth of shaft.

Then, $$N = \frac{(D^2 - d^2) \times .7854 \times x}{t \times b \times l}. \qquad (87.)$$

All dimensions must be in feet, or all in inches.

EXAMPLE.—If the outer diameter is 18 feet 6 inches, the inner diameter 18 feet, and the depth of the shaft 100 feet, and the size of the bricks is 8 inches by 3 inches by 4 inches, how many bricks will be required to line the shaft?

SOLUTION.—Substituting values, we have

$$N = \frac{(18.5^2 - 18^2) \times .7854 \times 100}{.25 \times .3333 \times .66666} = 25{,}800 \text{ bricks. Ans.}$$

As before stated, this is only an approximation, for as a general thing the number of bricks found by this formula will be from 10% to 15% more than will be required.

1488. Mortar.—In shaft lining, mortar should be used sparingly, and when water is to be resisted, good Portland cement should be used. In less important work, use equal parts of cement, lime, and ground ash clinkers (sand is too heavy) well mixed. To avoid getting mortar joints too thick, let the mason spread his mortar at a little distance from the spot where the brick is to set, then place the brick in it and slip it by gentle pressure into its proper place. The brick will carry sufficient mortar with it for its bedding.

cement, and concrete is rammed into the space between the segments and the sides of the shaft. Above each cement block a thin layer of cement is spread, and on this the segments of the ring above are placed. (See *b*, *b*, Fig. 439.)

In some cases a double ring of cement segments is employed (*J*, *J*, Fig. 439). Here a course of cement blocks for the back wall is first laid, and cement rammed in behind. This course is about half a block higher than the inner layer, so as to break the horizontal joints. The courses of the inner ring are then laid in such a way that the vertical joints do not coincide with those of the back ring. The joints are carefully filled with cement, and the intermediate space of about 4 inches between the inner and outer rings is then filled in with concrete tightly rammed. In this manner a thoroughly water-tight tubbing is obtained.

1494. In shaft sinking, cement is found to be a valuable auxiliary, particularly in the special setting of masonry known as coffering. Cement, too, has been employed in an ingenious way for consolidating shifting sand in water-bearing strata. The method employed consists in injecting powdered cement, by means of compressed air, steam, or water under pressure, into the ground to be consolidated. The cement is screened in order to free it from lumps, and the powder is taken by an injector which forces it through a flexible pipe into a perforated tube sunk in the soil to the required depth. In this manner the soil becomes impregnated with the powdered cement, while the water is driven away from it.

THE PROCESS OF SINKING.

DRILLING.

1495. When, in shaft sinking, ground is reached that is too hard to be excavated by the sinking pick (which is simply a heavy pick made like the ordinary mining pick) and wedges, explosives are used. The operation of blasting consists in boring holes of suitable diameter and length in favorable positions in the pit bottom, in inserting the charge of the explosive compound in the lower portion of the hole, in filling up and ramming with suitable material the remaining portion of the hole, and in exploding the charge. These holes are made either by "churn drills," "jumpers," or power drills.

1496. The **churn drill** is a bar of round iron, swelled in the center to give weight, having a bit on each end. This is raised and forced down by the hands of one or two men in the same manner as a percussion boring machine makes its stroke. It is turned slightly at each stroke to keep the hole round.

In the shaft bottom the conditions are frequently such that the holes must be drilled at different angles. So long as the boring is vertically downward, or the angle from the vertical is slight, the churn drill is very effective. But in sinking operations, holes must be drilled at all angles, and it is obvious that in some of these directions the churn drill is practically worthless. To meet these conditions, the ham-

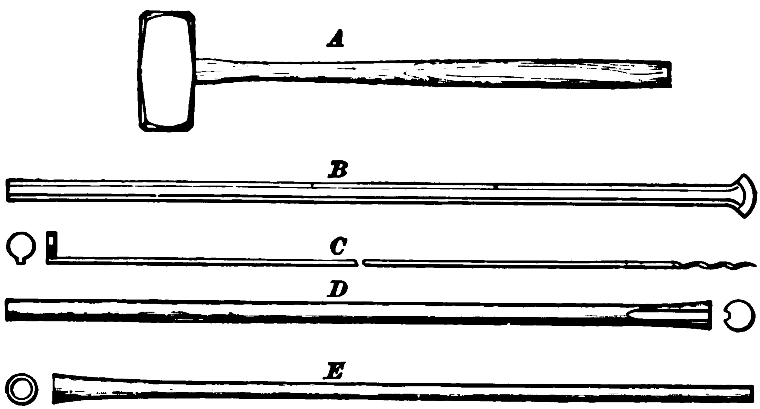


FIG. 440.

mer and jumper shown in Fig. 440 are used. This figure shows a set of double hand rock tools.

A, sledge hammer, weight 5 pounds or more.

B, drill, of which there are usually three in a set, the dimensions being 18 inches long, with $1\frac{1}{16}$ inches cutting edge; 27 inches long, with 1¾ inches cutting edge; 40 inches long, with 1⅝ inches cutting edge.

C, scraper and drag-twist.

D, rammer, or copper-headed tamping bar.

E, bêche.

1497. The method of using these tools is as follows: The hole having been started, the short drill is inserted and held in position by one man, while the other, called the "striker," strikes the top of the drill with the sledge hammer. The man holding the drill gives it a slight turn after every blow so as to ensure a round hole. After the short drill has gone in about half way the second drill takes its place, and after that the long drill. The scraper is a thin iron rod with a round, flat end, turned up at right angles to the stem, for the purpose of scooping all the sludge and débris from the hole. The drag-twist at the other end of the scraper is a spiral hook. To ensure the hole being thoroughly clean and dry, a wisp of hay is pushed into the hole and the drag-twist is then inserted until it becomes entangled in the hay, which can then be removed.

When the hole has been cleaned, the charge of explosive is inserted and the fuse laid to it. The hole now needs tamping, and this is done by plugging it up by means of the tamping bar *D*. It will be observed that there is a groove cut out along one side of this tool, the object of which is to allow for the space occupied by the fuse along one side of the hole, when the clay is being tamped or rammed. The bêche *E* is simply a rod with a tapered hollow end for the purpose of extracting a broken drill, if necessary.

1498. In extra hard rock the diamond drill, shown in Fig. 441, and the rock drill, a type of which is shown in Fig. 442, have been used to advantage. These may be operated by steam or compressed air; the latter is most commendable for the comfort of the sinkers, but from a point of economy steam may take precedence.

work. This slide being say 18 inches long, the hole can be drilled that depth. When this depth is reached the screw is reversed, the drill drawn out of the hole, and a longer drill placed in the hole and fastened to the piston. The second drill is rather narrower than the first, so that it will not catch on the sides of the hole. When the entire length of this drill has been bored, if it is still necessary to go deeper, a third and then a fourth drill can be added.

Percussion drills may be used to put in any number of holes desired, and at any angle. The number of holes and their position will depend upon the form and size of the shaft. The holes generally vary in depth from 3 feet to 4 feet, and in diameter from 1¼ inches to 2 inches.

Sumping holes are the first holes drilled and fired in a level pit bottom. They should be placed near the center, and inclined at an angle of from 20 degrees to 40 degrees, and should not be too deep, say 3 feet in hard rock.

BLASTING BY FUSE.

1500. In blasting by fuse, frequently four or more holes are lighted at the same time, lengths of fuse being used, so that the shots go off one after the other, allowing each detonation to be counted, so that the sinkers may know if all have fired. Fuse blasting is objectionable, because, under many conditions of sinking, the simultaneous discharge of blasts gives the best results. As each shot mutually assists the other, the result is about 1.4 times as powerful as that obtained from consecutive firing. Fuse firing is dangerous, because the fuse may hang fire.

Time fuses are in use at present, but they can not be relied upon under all circumstances, and especially when subjected to the varying conditions of damp holes. Time fuses are made of cotton or hemp, either single tape or double tape. Some are made of gutta percha, and others of an outer and inner casing of special material, according to the conditions under which they are to be used. The best is inferior to the electric exploder.

The cap should be inserted only $\frac{3}{4}$ of its length to avoid such an occurrence. After inserting the cap, close the end of the cartridge, and tie securely with a string, as shown in Fig. 445. The cartridge so prepared is called the **primer.**

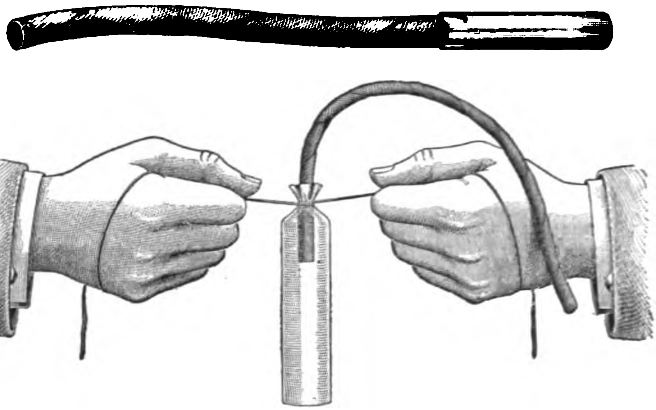


FIG. 445.

When a number of cartridges are inserted in the same hole, the detonation of the *primer* is sufficient to explode the entire charge. The size of the cartridge should be such as to fit fairly snugly in the hole. The cartridges must be inserted and pressed home carefully, one by one, the primer being inserted last and pressed tightly down upon the charge, and then the "*tamping*," or "*stemming*," should be inserted.

1503. Holes are charged by putting in one or more cartridges, and squeezing each with a wooden rammer. The best tamping for a drill hole is that which will not blow out; it must be of a strong resisting character—something which changes form when disturbed, and which tends to wedge. The best tamping, except small stones, is sand, and the worst is wet clay. If substances which are near at hand will serve the purpose, they had better be used.

The power of the explosion is improved by good tamping, because it confines the forces generated by the blast within the hole. In order that even nitroglycerin explosives may be well tamped, a soft substance, such as clay, is put directly on top of the cartridge, and gently pressed home; on top of this, the tamping may be rammed tighter and tighter as it comes nearer the top of the hole.

ELECTRIC BLASTING.

1504. The American method of electric blasting depends upon the generation of a current of electricity in a similar manner to the production of electricity for lighting purposes, the current producing incandescence in a wire which is submerged in an explosive. A magneto-electric machine is simply a small dynamo operated by hand, the electric current being produced by the rapid revolution of an armature, or a coil of wire, between the poles of a magnet. The current is generated in the machine, and when it is at its greatest intensity, it is discharged into the circuit which contains the exploder. In this way the electric current passes over a fine platinum wire bridge, which offers so much resistance that the wire becomes red hot, and this heat explodes a small quantity of fulminate of mercury which is in the cap.

1505. Fig. 446 shows a cap with wire connections. The wires *C*, leading from the battery, are connected by a fine platinum bridge *E D*. *F* is a cement, usually made of sulphur, for the purpose of holding the ends of the wires intact,

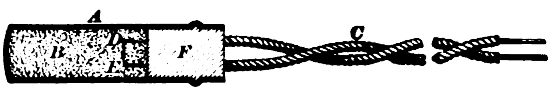


FIG. 446.

and serving to seal the mouth of the exploder. *B* is the fulminating mercury. The whole is encased in a tube *A*, which is similar in appearance to a gun cartridge. It is about 1¼ inches long and ¼ inch in diameter. The wire *C* should be of pure copper, of about No. 20, American wire gauge, and well insulated by cotton or other substance, wound double over the wire.

The passage of electricity through any substance is practically instantaneous when compared with the passage of heat. Therefore, in a hole where there are several cartridges, to ensure immediate explosion of all of them, an exploder should be placed in every second or third cartridge; the best result will be secured if there is an exploder in each.

When blasting is done under water (the result accomplished is then only ¼ that of dry blasting), and whenever the explosive is gelatin, gun-cotton, forcite, or dynamite, the double strength exploder should be used.

1506. The greatest explosion that can be made is produced when the detonation is sufficient to ensure the immediate explosion of the entire charge. If dynamite which has frozen is not thawed out, it will take a much higher initial explosion of detonation to set it off. In some cases, several ounces of powder are put in the hole in contact with the exploder and on top of the dynamite, in order to produce the large amount of shock and heat to discharge the higher explosive—dynamite.

1507. The explosion is simply the conversion of the solid into a gas. The gas occupies more space than the solid; hence, in the tendency to expand it breaks the rock. The higher the grade of the explosive the more sudden is the conversion into gas, and the more effective is the blow which it delivers in the drill hole. This suddenness of conversion into gas is sometimes of more importance than the number of volumes of gas produced by a certain number of cubic inches of the explosive, as it increases the amount of work done.

1508. For firing by electricity, two systems of connecting the wires to the machines are in use. In the first, Fig. 447, the fuses are connected in **series**; that is to say, one wire of the first hole is connected to one wire of the second hole, and the other wire of the second hole to one wire of the third hole, and so on, until all are joined, when there will be one wire of the last hole and one wire of the first hole left unconnected. These are now joined by wires to the machine, which is in a place of safety.

1510. Electric Blasting Apparatus.—Fig. 451 shows a good type of magneto-electric machine, weighing about 16 pounds and occupying less than ½ a cubic foot of space. These machines are of different capacities; one kind will fire 15 holes, while another kind will fire from 25 to 40 holes. With these machines no uncertainty exists.

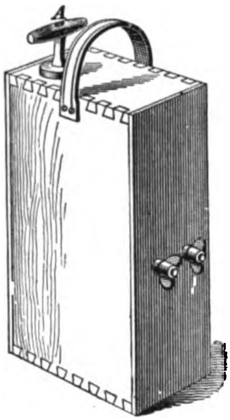


FIG. 451.

In using these machines a fuse, or exploder with two wires attached, is used as already described. The charges having been connected as directed (the leading wires being long enough to reach a point at a safe distance from the blast) and all being ready, the workmen connect the leading wires, one to each of the winged nuts on the front side of the machine. This is accomplished by placing the wire between the nut and the shoulder and tightly screwing the nut against the wire.

To fire, take hold of the handle *A* and lift the rack (or square rod, toothed upon one side) to its full length, and press it down, for the first inch of its stroke with moderate speed, but finishing the stroke with all force, bringing the rack to the bottom of the box with a solid thud, when the explosion will take place.

EXPLOSIVES.

1511. M. Berthelot describes nitroglycerin as "really the ideal of portable force. It burns completely without residue—in fact, gives an excess of oxygen; it develops twice as much heat as powder, three and a half times more gas, and has seven times the explosive force, weight for weight, and taken volume for volume, it possesses twelve times as much energy."

1512. The name "high explosives" is generally applied to that class of explosives of which nitroglycerin is the active principle. They are commonly known by the name of **dynamite.** This usually burns freely without explosion when unconfined in the open air, but when fired by a blasting cap it explodes with enormous force.

All nitroglycerin compounds freeze at 40° F., and resume their soft, pasty condition upon being warmed. To secure its full explosive power, dynamite must never be used in even a semi-frozen state. All nitroglycerin compounds decompose when exposed to the direct rays of the sun for any length of time, whatever the temperature of the air may be, and hence lose their efficiency. All frozen cartridges should be thawed; as, when frozen, the powder loses much of its efficiency, its properties change and it is difficult to explode it with a cap.

1513. When the cartridges are frozen, they should not be exposed to a direct heat, but should be thawed by one of the following methods:

1. The number of cartridges needed for a day's work should be placed on shelves in a room heated by steam pipes or a stove. If a small house is built for this purpose, it should be banked with earth, or preferably fresh manure.

2. The cartridges may be put in a water-tight kettle and this placed within a larger kettle, filling the space between the kettles with water at 130° F. to 140° F., or at such a heat as can be borne by the hand. If the water cools, it should not be reheated in the kettle, but fresh warm water should be added. The kettles should be covered to retain the heat. The temperature should not be allowed to get above 212° F.

3. When the number of cartridges to be thawed is small, they are sometimes placed about the person of the workman until he is ready to use them, but this is a dangerous practice.

Cartridges should not be thawed by putting them in hot water or by exposing them to live steam, as this (unfortunately very common) method has an injurious effect on the powder. Neither should they be thawed by holding them in the hand before a fire. Cartridges exposed after ditions of each case; but these modifications must, in some respects, be radical, and the best results will be obtained by adopting from each of the several systems the methods and appliances that are best suited to the case.

In order to pass through quicksand, special means are employed, the principal ones being (1) the Piling method, (2) the Drum method, (3) the Gobert or improved Poetsch sinking process, and (4) the Triger method.

PILING METHOD.

1516. When the quicksand or other soft material is near the surface, the method of piling shown in Fig. 452 is employed. This requires the shaft at the commencement of the soft material to be very large, especially where it must be carried to a considerable depth.

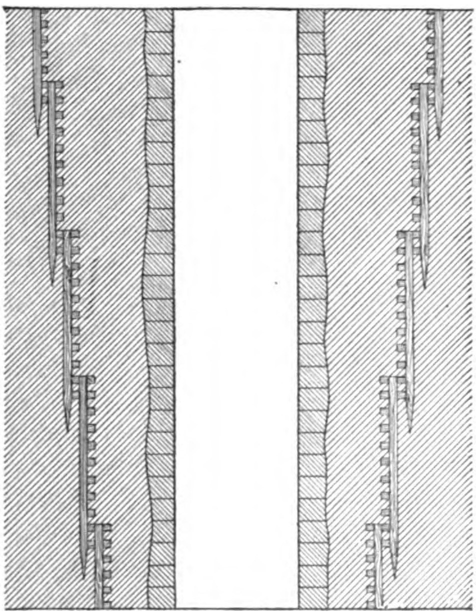


FIG. 452.

In such a case, a wooden curb of the size and shape of the opening is laid down in its true position. This may be made of oak about 9 inches wide and 6 inches thick. Outside of this, and all around it, piles from 6 inches to 9 inches wide and 3 inches thick are driven as deep as possible without breaking. After the first set of piles have been driven at the surface, excavation is started. When the excavation reaches a depth of about ¾ the length of the piles, the work is squared up, and the second set of piles is driven within outside is perfectly smooth, and meets with little resistance in passing through the ground. The joints between the segments are filled with sheet lead, the segments being drawn together by bolts. The ribs are made broader where weights have to be used to sink the drum, and the cutter (Fig. 456) is attached to the bottom segment.

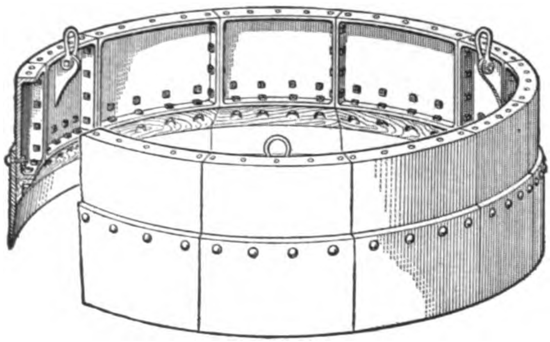


FIG. 456.

Sometimes the drum will sink too fast, and unevenly. To avoid this, the tubbing is hung at three, four, or more points by chains and a lowering screw arrangement from transverse beams at the surface. The speed can in this manner be regulated at will, and when boulders, or any other obstructions, are met, they can be removed to prevent canting the drum.

1522. Cast-iron drums are not suitable for unequal strains, so in work where such strains are expected wrought-iron drums should be used.

Fig. 455 shows a drum with five tiers of segments above the cutter *A*, and Fig. 456 shows a perspective view of the cutter.

THE IMPROVED POETSCH, OR GOBERT FREEZING PROCESS.

1523. When beds of quicksand are met at considerable depths below the surface, the foregoing methods are impracticable, and are replaced by an ingenious method known as Gobert's freezing process. In this system, tubes are forced through the water-bearing strata, and such a degree of coldness is produced within the tubes that a cylinder of ice is formed around them. By placing the tubes in the proper position, an ice wall or dam may be formed around the line of shaft, or if sufficient time be given for the freezing, a solid mass of ice will form directly below the shaft, enabling the workmen to continue the sinking with unusual rapidity and a fair degree of safety.

1524. In Fig. 457 are shown a vertical and horizontal section of a shaft where this system is applied to a bed of quicksand about 30 feet thick and producing such a quantity of water that the pumps can readily keep it to the level of the bed. The vertical section *A* is taken on the line *D* and the horizontal section *B* on the line *E F*. Large wrought-iron tubes *p*, about 8 inches in diameter, are driven into the quicksand at such an angle that the permanent walling can be put in without removing them. These tubes are connected together at the top by cast-iron fittings *c*, and provided at the bottom with a circular shoe *s* to facilitate the passage of the tubes through the quicksand. They are also closed at the bottom, after being driven to their permanent position, by a lead plug *n* and several alternate layers of cement and pitch *l*. Within each tube *p* is placed a small tube *t*, having a helicoidal or serpentine shape, and provided at the top with a valve *v* to regulate the inflow of the liquid which produces the lowering in temperature. The tubes *t* are also connected together above the valves *v*.

1525. When the system is properly connected, anhydrous liquid ammonia is forced from the refrigerating plant at the surface down the tube *q* into the small serpentine tubes *t*, along which it is allowed to escape into the tubes *p* through small orifices *h* placed in the valley-beds of these tubes. The liquid continuously flows in thin streams through the orifices, vaporizes, and, consequently, takes up a great deal of heat from the surrounding strata, causing them to freeze. This vapor is forced through the tube *c* to the refrigerator, where it is deprived of its heat and again compressed into a liquid ready to return through the tube *q*.

The pressure within the tubes p is almost invariably less

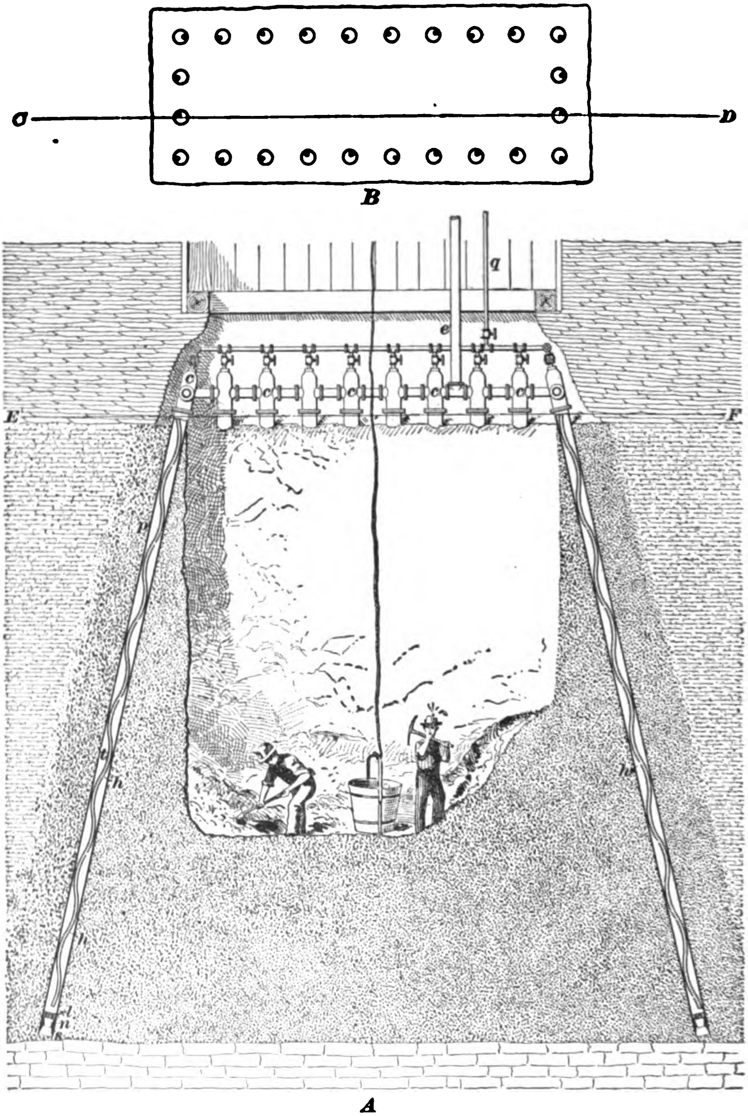


FIG. 457.

than the external pressure, thereby preventing any possibility of the liquid flowing out in case of a break in any of

The compressed air enters the chamber V by the pipe A. The water within the tube is then pressed out through the pipe W. The mode of entering and leaving the chambers is interesting, and is as follows: It seldom (or never) happens that the valves D_2 and D_1 are open together when D_3 is closed, it being so arranged in the figure only to make the details plain.

Suppose it is necessary for gravel and stones to be lifted from V into T, or for the workman in V to pass up into T. The valve D_3 is then closed by a workman in the middle chamber, who also opens the small tap E, and in a short time the pressure in T is equal to the pressure in V. The workman in V then opens the valve D_2, when he can pass into the middle chamber T; or stones and dirt can pass from V into T. If a change of workmen is to take place, one passes into V, and closes D_2; the man in the middle chamber is then relieved by the tap H being opened; D_3 is then opened, and the two men change again. The man passing into T shuts D_3, and opens E to equalize the pressure between T and V, and the man in R opens K to equalize the pressure with that of the atmosphere, when he can open D_1 either to discharge dirt or pass out himself. The pulley P is used in raising or lowering men or material through the valves D_2 and D_3.

After a bed of rock is reached by this process, the inside of the cylinder is lined with brick to prevent damage to flanges which might occur in working the shaft for mining purposes.

1529. The depth which can be reached by this method is limited; for the pressure of water outside the cylinder increases with the depth, and a higher pressure of air must be used in the lower compartment to stop the inflow of water. A point is soon reached at which sinkers can not work. As much as 121 feet of quicksand have been passed through by this method, the greatest atmospheric pressure being about 41 pounds per square inch.

There are other pneumatic systems, but they are all subject

Fig. 459, is differently constructed, according to the nature of the ground it is intended to cut. When intended for cutting soft material, the bar in which the teeth are attached is suspended by a fork of wrought iron; but where hard rock is to be cut, the bar is to be forged in a single piece and weighs from 18,000 to 22,400 pounds. The steel teeth fit into sockets in the main bar, and are additionally secured by a pin, which is readily driven out when the teeth must be sharpened or renewed. The instrument shown in Fig. 459 is capable of advancing 8 feet per day in ordinary ground. The arm *A A* is for the purpose of steadying the motion of the machine and is slightly larger in diameter than the lower part *B*. The teeth *C*, *C* on the arm *A A* widen the hole slightly and trim off the edges.

1534. When the cutter or trepan has done work for some hours, usually at the rate of 9 or 10 strokes per minute, sometimes at about 20 strokes per minute, it is raised by a small hoisting engine, with a flat hemp rope 14½ inches wide by 2⅝ inches thick, and by the successive unscrewing of rods. The hole is then cleared by means of a sheet-iron cylinder, about 6 feet in length, with two valves in the bottom, which is lowered and raised by the rods. On being worked up and down and turned in the same manner as the cutting tool, the débris is drawn into it; and when it has sunk to its depth in the loose stuff, it is raised, the valves close, and the material is brought to the surface.

1535. The larger cutter, or trepan, Fig. 460, which weighs about 36,000 to 49,000 pounds, is similarly formed of a wrought-iron bar having teeth attached for that portion of its length which exceeds the diameter of the smaller excavation. It is guided below by a cradle or iron bar *C*, which fits closely within the smaller excavation.

The teeth are so formed and set that they always cut the bottom of this second stage into a sloping surface, so as to allow the fragments to roll into the smaller shaft, where they are caught in a sheet-iron bucket which has been previously lowered into it. The rate of progress in ordinary ground,

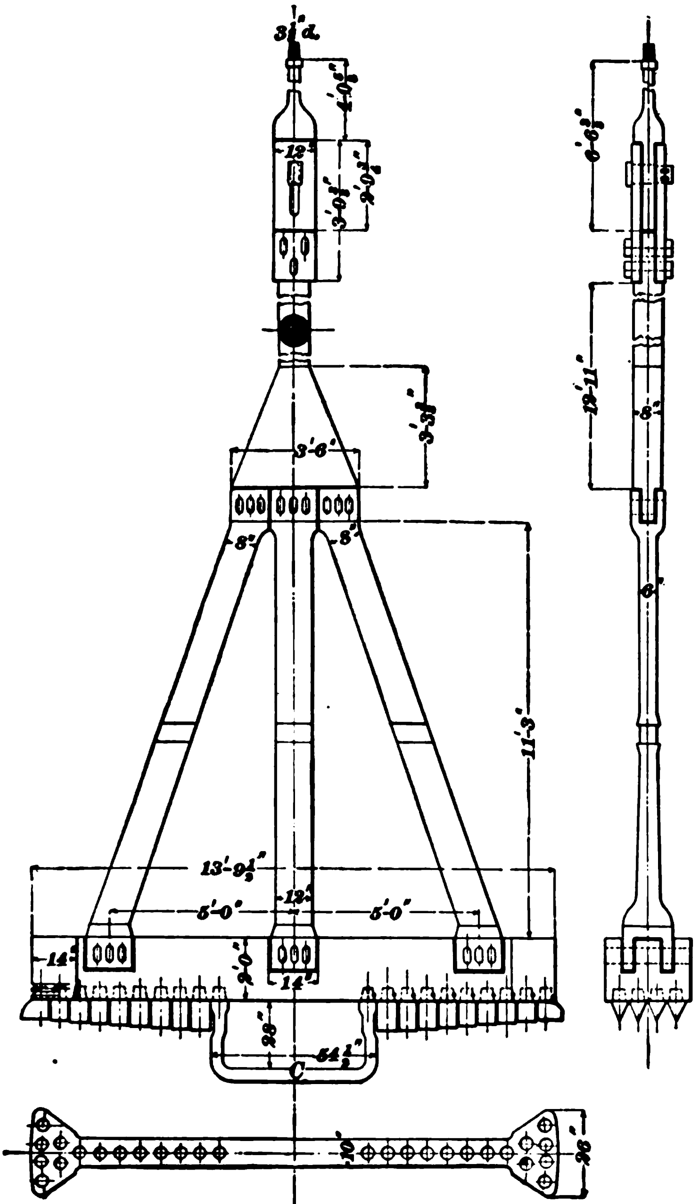


FIG. 460.

when all is going well, is about 40 inches per day; but in hard rock the rate will not exceed 10 inches per day.

1536. In order to obviate the tremendous vibration which would be imparted to the rods by tools of this great weight, a special arrangement is necessary in order that the heavy rod and cutting tool, which together are 36 feet long, may be "free falling," the balance of the rods being used simply to raise the cutter to the desired height of stroke. To accomplish this, a slide piece of great strength is used in a manner resembling the "jars" in the American rope method of boring.

The guides of the smaller trepan are set at right angles and formed of two strong iron bars. In the case of the larger trepan, one cross-piece only is rigid; the other one, at right angles to it, is hinged on both sides of the main rod in such a way as to be lowered or raised during the shifting of the tools. These folding arms, when required to be used, are brought into position when the tool is ready for work. The guide then forms a cross, through the central opening of which the rod of the tool slides freely up and down.

Figs. 459 and 460 show the dimensions of the tools for boring a shaft 14 feet in diameter.

1537. The most remarkable part of the operation is the fixing of the tubbing, Fig. 461, without the use of pumping engines, in such a manner that it securely dams back the water in the measures sunk through. The lower ring of the tubbing is, like all the upper portion, cast in a single piece. Its bottom flange *A*, which comes to rest on the bed or seat cut in water-tight ground, is turned outwards, and its upper flange *B* inwards. Upon the lower flange, and all around the ring, a wall of well-picked moss *C* is tightly packed. This moss is enclosed in network while being lowered to position. To aid in the forcing of the moss against the side of the shaft, small sheet-iron springs *D* are placed above and below, as seen in Fig. 461, which have the effect of giving the pressure a definite direction. The next ring *E*, which is large enough to slide down on the outside

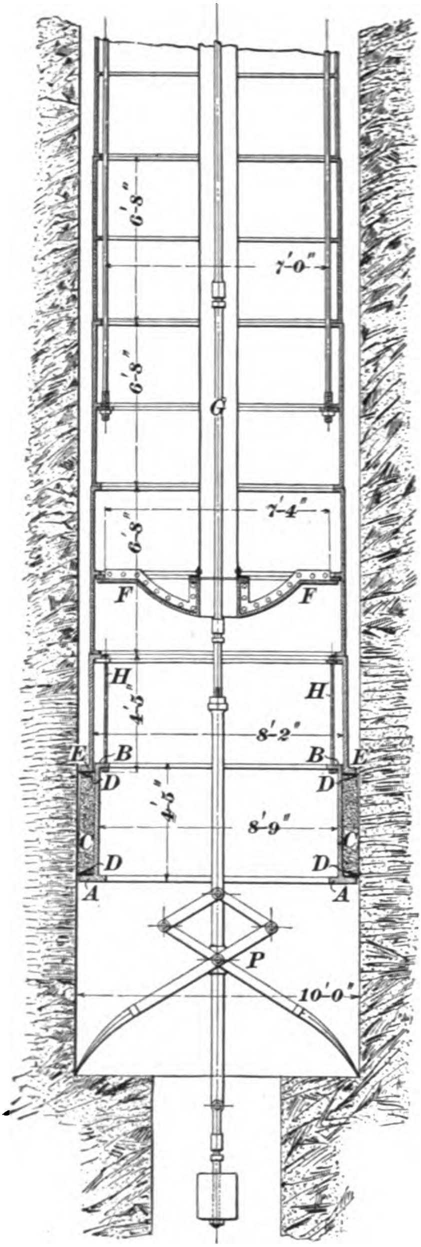


FIG. 461.

of the bottom piece, rests on the moss cushion by a flange also turned outwards. As soon as the moss is pressed down by the weight of the ring *E*, the ordinary rings of the tubbing are built upon it, as before, and their weight continues to compress the moss until it is practically solid. Each flange is planed, and between them a ring of sheet lead $\frac{1}{8}$ inch thick is laid, which, after screwing up the bolts, is beaten in on both sides with hammer and chisel.

The tubbing is of extra thickness, and each ring is generally made $4\frac{1}{2}$ feet to 5 feet high. The lower ring is $2\frac{3}{4}$ inches thick, and the upper ones are made gradually lighter. In order to facilitate the gradual lowering of this enormous weight by the six rods and screws used for this purpose, a diaphragm or false bottom *F* is attached by screw bolts near the bottom of the tubbing, which causes it to float on the water. A central equilibrium tube *G* passes up

2. The water pressure in the shaft to a great degree prevents the inflow of quicksand or other soft material.

1539. The Lippman System.—In this system the hole is bored any required size from the beginning by a large trepan having a cutting tool bifurcated at both ends, or shaped like a **Y** at each end. This form of trepan, shown in Fig. 462, is adopted in order that the blows near the circumference will be approximately as close as those near the center. In this system, the engine gives motion to the boring lever by means of an endless chain and an eccentric, which prevents all shock. For removing the débris, an iron box divided into three compartments, each compartment having nine holes closed by valves opening inwards, is operated just as is the sheet-iron cylinder used in connection with Fig. 459. This iron box must generally be filled twice before boring can be resumed.

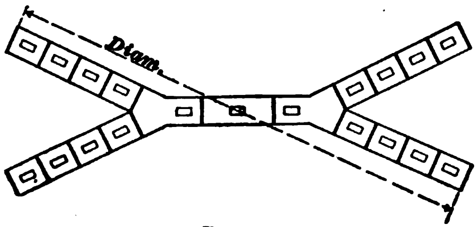


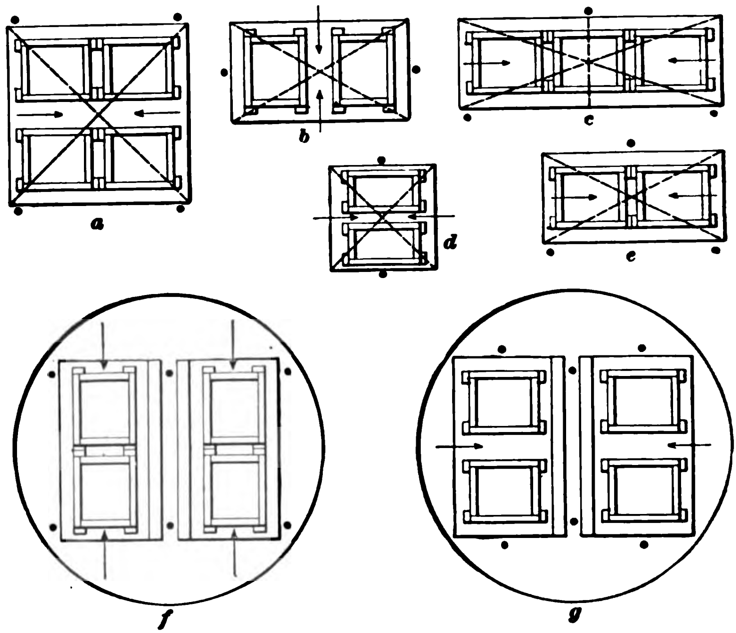
FIG. 462.

The sides of the shaft are secured in a similar manner to that employed in the Kind-Chaudron system.

THE LONG HOLE SYSTEM.

1540. This process consists of drilling holes from 100 to 300 feet deep, or more, and close enough to each other (3 to 4 feet apart) to be used for blasting. When the drills are taken out of the holes, the holes are filled up with sand. The sinkers then usually drill sumping holes in the center and blast out the rock. They then remove 3 or 4 feet of sand from the long holes. The inner group of long holes is always fired first, and the outside rows afterwards. The outside holes generally square the shaft nicely, so that little dressing is required. When the bottoms of the holes are reached, the drills are again put at work.

into chairs made fast on the buntons and on the sides of the shaft timbers. The rails should be fastened together by fish-plates attached to the back of the rail. In such a case



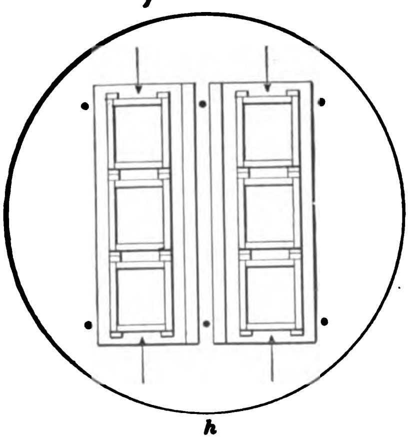


FIG. 464.

the joints are between buntons. A small space should be left between the ends of the rails at the joints for expansion, and the holes in the fish-plates should be made oval, so that the bolts are free to move up and down, as required by expansion and contraction, without any lateral play.

1550. Wire Rope Guides. — Where wire rope conductors are used in deep shafts, the clearance must be more than with rigid conductors, because of the vibration that is set up in the guide ropes by the running cages.

Fig. 464 shows the various arrangements for wire rope guides for the different arrangements of the cages.

At *a* is shown a cage with four cars and four wire conductors; at *b* is shown a cage with two cars and two conductors; at *c* is shown a cage with three cars and three conductors; at *d* is shown a cage with two cars and two conductors; at *e* is shown a cage with two cars and three conductors; at *f* is shown two cages with two cars each and two conductors each, and flat rope or safety conductors between. Two conductors, both on one side of the cage, are used, and between the cages, and unconnected to either of them, two other ropes are suspended. These latter ropes are often flat (not always), and at the passing point are lined or covered with steel or copper strips which prevent any possibility of the cages colliding when the clearance is very little. At *g* is shown two cages with two conductors each and two cars each; at *h* is shown two cages with three cars each and two conductors each.

The arrows show the direction in which the cars are run on to the cage, and the dots show the position of the guides. The dotted lines show the position of the cage chains.

1551. Wire rope conductors, like T-rail and other iron guides already mentioned, are subject to expansion and contraction. This is provided for in the following manner: Each conductor is made secure at the top of the head-frame with two or more wrought-iron clamps. These clamps grip the conductor and rest upon timbers of sufficient strength to safely carry the greatest weight necessary to keep the conductors taut. Care must be exercised in fitting the clamps nicely to the guides; otherwise, instead of holding the conductors firmly, the clamps may actually nip and tend to break them.

At the lower end, in the sump, heavy weights are placed upon clamps, one or two pairs gripping the conductors. The weight varies according to the depth, but a fair rule is 2,240 pounds for each 600 feet of the depth.

1553. In commencing a slope, the ground is excavated in an open cut, precisely as a railroad cut is made, the sides being trimmed back to the angle of repose, or made perpendicular and supported by crib work. The excavated ground is thrown out by hand or removed by wheelbarrows. When the face of the cutting has a greater vertical height than the total height of the timber to be used, the sinking of the slope is commenced in the following manner:

Sufficient room is first excavated for a set of timbers in advance of the one set up where the open cut was discontinued. Where the ground is friable, as it frequently is at

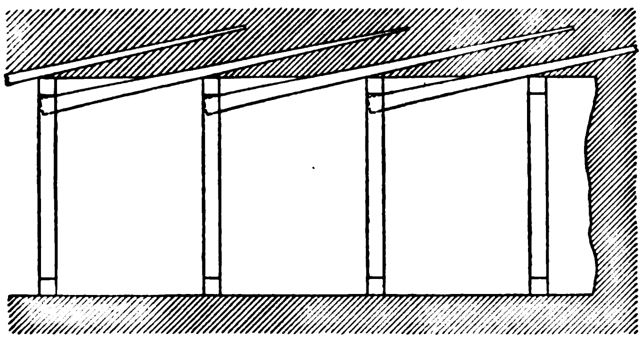


FIG. 466.

shallow depths, lagging of timber (usually 3-inch or 4-inch plank on top, and 2-inch or 3-inch plank on the sides in well-finished work) is securely placed. The lagging is made flush with the front of the first set of timbers, but on each set thereafter, it reaches from center to center. Sometimes, the ground is so soft that **forepoling**, or piling driven in the roof in advance of each set of timbers, is employed (see Fig. 466), so that the timbers can be put in without removing an unnecessary amount of material.

1554. Frequently, the overhead lagging is put up by cutting a trench from the top to the bottom of the face of the slope, from 12 inches to 18 inches wide, the one end of the lagging board resting on the last set of timbers, and the forward end resting on a temporary prop of suitable length.

1560. Fig. 481 shows the provision made to keep the track in place, that is, to prevent it from slipping down the pitch in the slope. The long ties are shown resting against the legs in the lower portion of the figure; the middle shows the arrangement of the roadbed when only a center prop is used, and the upper part of the figure shows the arrangement when no timber is used; *a a'* are long ties, *b b'* are the regular ties, and *c*, *c*, *c* are braces to keep the ties in proper place.

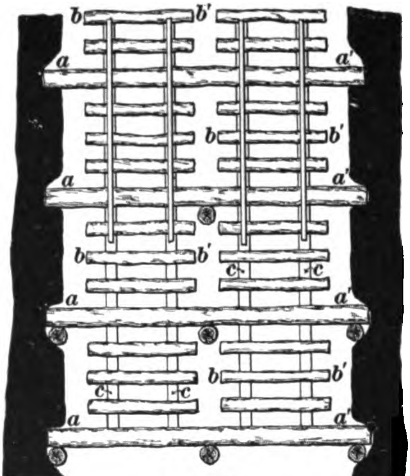


FIG. 481.

When square sets are used or where the sills of round sets are hewed on the upper side, a long tie is spiked upon it, or the sill itself may take the place of *a a'*, but this requires greater care in ballasting and "lining up" the tracks.

1561. Where the dip does not exceed 40°, the height of the slope is made about the same as the height of the entries or gangways, but it is never desirable to have the height less than about 6 feet.

Slope timbers are set leaning up the pitch a few degrees less than right angles to the dip, for reasons given hereafter.

1562. There are many methods of jointing timbers, but those given are as good as any forms in common use.

In the notching of timbers, there is a general principle of right and wrong. The joints should be cut so that every square inch shall have a uniform bearing. If the joint is poorly fitted, the whole weight will be thrown on a small surface, which will give way.

Care must be taken not to reduce the strength of the set too much by having too much spread, or batter, on the legs. Just what the batter should be is a debatable question, but it should not exceed 1 in 6 or 1 in 5.

1563. Where it is necessary or desirable to dispense with the center prop of a wide set of timbers, the following methods (Figs. 482 and 483) are employed. Besides the

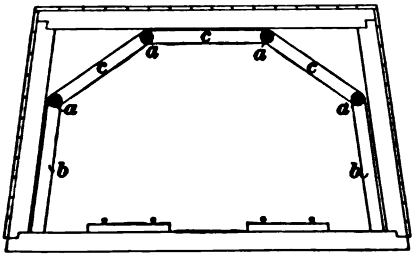


Fig. 482.

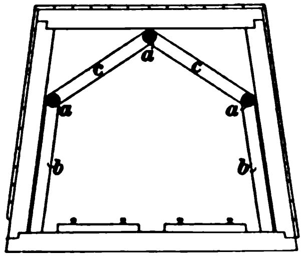


Fig. 483.

usual set of squared timber, there are pieces *a*, *a* running along the slope, with props *b*, *b* and braces *c*, *c*, the whole, as shown, approximating to the form of an arch.

WALLING.

1564. When the price of timber becomes more than that of brick, or where timber strong enough to give the

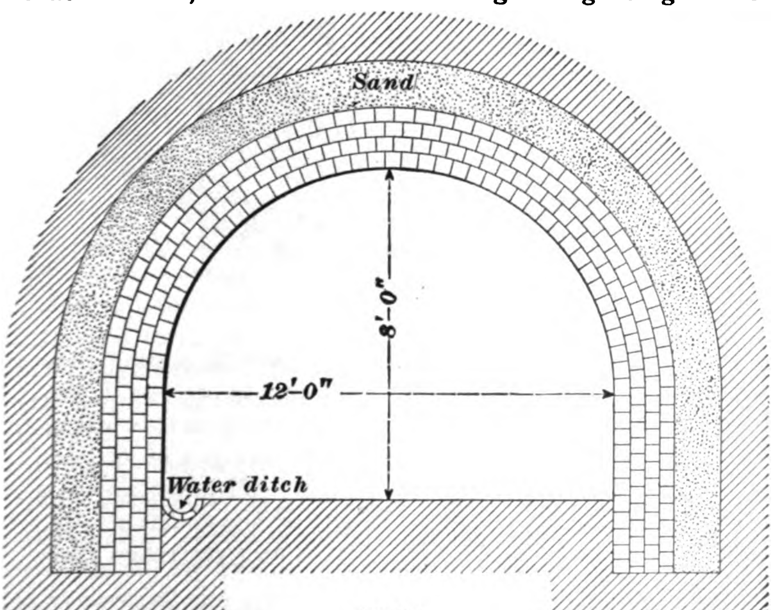


Fig. 484.

frames which have the form of the invert and arch), iron templates are used for turning the invert and arch.

Where a heavy lateral pressure is expected, the sides of

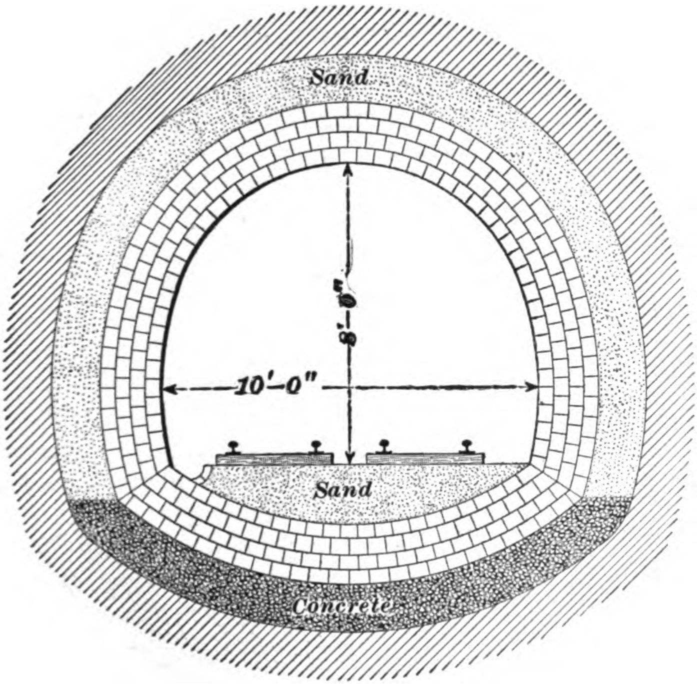


FIG. 486.

the arch should be concaved from their intersection with the invert, as shown in Fig. 486.

Fig. 487 shows an elliptical arched roadway, which is the strongest form that is suitable for mine roads. The circular is not practicable. The elliptical form will resist pressure from any or all directions better than any of the other forms given.

1565. Very little mortar should be used between the joints when building any one of these forms of arches. No old wood or anything subject to decay should be put in or left behind the walling. When there is considerable water in the strata, the space behind the walling should be filled in with concrete. At great depths the crush is enormous, and arches of great strength are thereby destroyed. It has been found that by packing the top and sides with sand to a

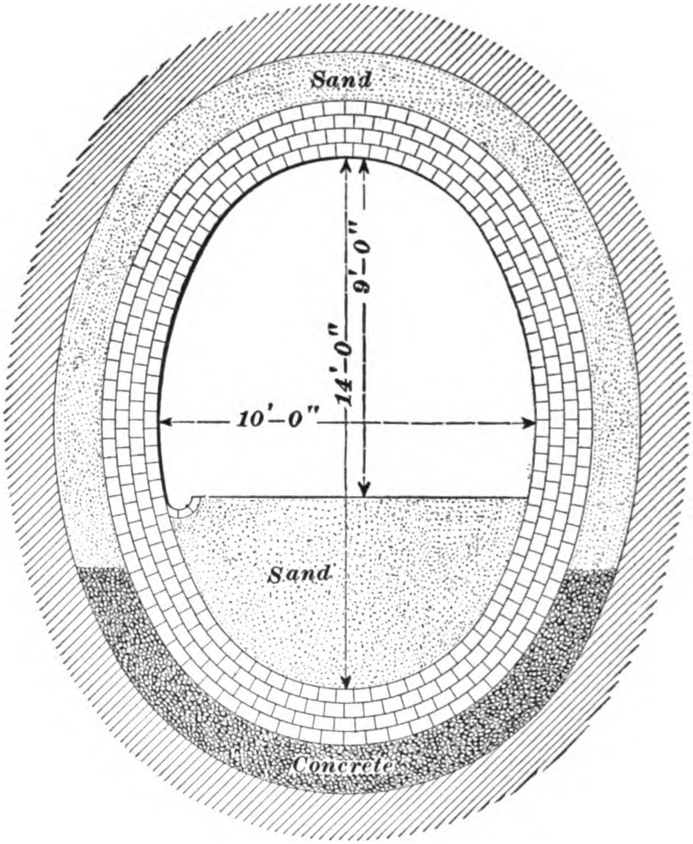


FIG. 487.

thickness of not less than one foot, the weight is distributed over the whole surface of the arch; consequently, it will stand a greater pressure.

SINKING OPERATIONS.

1566. In slope sinking, the operation of getting out the coal is accomplished in the same manner as when driving entries or gangways. The face is advanced by blasting out of the solid by means of flanking shots, alternating from one side to the other. Where the coal is hard enough to blast, but not too hard to shear, the coal is "shorn" in the center from top to bottom and the coal on either side of this shearing is blown off the solid. In soft coal it is necessary to mine the coal, which may be done on the top or bottom, as the water will permit.

1567. In thick seams, where water is coming in freely, the upper portion of the coal is removed in advance of the bottom, the coal left forming a sump for the water. This lower coal may be advanced by leading the water to a small hole dug in the bottom, from which it is drawn by the pump, until the shot has been placed and fired. In thin seams this method is not practicable. Here some small proportion of the whole width must be kept in advance, either in the center or sides, from which the water is pumped. When there is no water, slope sinking is comparatively an easy matter.

1568. In "rock slope" sinking, the operation is on much the same principle. When air drills are used, however, the center is usually advanced first. A great deal depends on the judgment of the sinker in charge, and his skill may change the manner of procedure from time to time in order to get the benefit of natural advantages.

The tracks, together with the timbering or walling, are carried forward simultaneously with the sinking.

DRIFTS.

1569. A horizontal, or nearly horizontal, opening driven in the coal from the surface above water level is termed a **drift.** When the seam of coal dips slightly inward, instead of starting the drift in the coal at the outcrop, it is best to start it some distance below and give it such a grade that when the drift is driven far enough for the first "parting" or "turnout," it will have reached the bottom of the coal seam. In this way an easy grade can be made for the loaded cars, whereby the haulage from the main parting to the tipple will be greatly facilitated. The cost of opening a drift in this way is but little greater than that

METHODS OF WORKING COAL MINES.

(PART 1.)

PILLAR AND CHAMBER METHODS.

SHAFT PILLARS.

1573. There are necessarily a great many methods of working coal mines, because coal not only varies widely in its physical properties, but is found in different strata, and at different depths and inclinations. All the methods, however, may be classified in a general way under two principal divisions, viz.: *Pillar and Chamber* and *Longwall* methods. Either of these two divisions may be so modified as to make it difficult to determine whether the modified method should be called Pillar and Chamber or Longwall.

1574. After a shaft has been sunk to the seam, the levels, entries, headings, gangways, or galleries to communicate with every part of the territory to be mined are turned off. Whatever the method adopted, no coal should be mined for a certain distance around the shaft except for the opening of roads. The pillars thus left should be large enough to protect the shaft from rupture.

1575. The size of the shaft pillar depends on:

1. *The Depth of the Seam.*—Because the pressure of the superincumbent strata increases with the depth.

2. *The Inclination of the Seam.*—Because the plane of fracture lies between the vertical and a line drawn at right angles to the pitch, and what is known as the "zone of subsidence" diminishes in height as the pitch increases.

The working of a seam causes the overlying strata to settle, and produces what is called "subsidence." If the seam is horizontal and not too deep, this subsidence will reach the surface and be greatest at a point vertically over the center of the excavation; but, if the seam is deep-seated, the settlement may not be perceptible at the surface. In case the subsidence reaches the surface, its limits bound what is called the **zone of subsidence.** If it does not reach the surface, a dome is formed, and we have what is termed the **dome of subsidence.** When the strata are homogeneous and horizontal, the dome of subsidence is symmetrical and its axis is vertical; but when the strata are inclined, the dome is not symmetrical and its axis is inclined. As the inclination of the strata approaches the vertical, the height of the dome becomes less. When the zone of subsidence crosses strata of varying inclinations, the axis of the dome is deflected; and, if the strata are soft and loose, the dome may reach far beyond the limits of the excavation, especially if the strata contain water. In all cases the plane of fracture of stratified rocks lies between the vertical and a line perpendicular to the strata.

3. *The Nature of the Overlying and Underlying Strata.*—Because the nature of the strata affects the *domes* variously, that is, the hardness, elasticity, plasticity, compressibility, etc., are conditions which affect the result. If the rocks are hard and brittle, the fall increases in volume much more than if they are plastic. If they are firm and cohesive, they yield only under forces very much greater than those which suffice to draw away soft strata. If it has elasticity, it transmits to a greater distance the pressure which it receives. The compressibility of rocks after expansion is also very variable. Therefore, over identical excavations domes are formed which differ in length, height, and width. When water is present with a soft fireclay bottom for the seam, it makes the protection of the shaft more difficult. The excessive pressure on the pillar of coal compresses the fireclay and also forces it up on the roadways, from which it must be removed; the process may go on indefinitely if the pillar is not very large, and may eventually destroy the alinement of the shaft.

4. *The Texture of the Coal.*—Because harder coal can withstand more pressure without crushing than softer coal, and is not so much affected by atmospheric influences.

5. *The Thickness of the Seam.*—Because the dome of subsidence, as a rule, develops in breadth and in height with the height of the excavation; however, there seems to be no direct ratio in the amount of subsidence to the height of the excavation.

It follows from the above considerations that in pitching seams the rise side pillars should be the larger, as shown in Fig. 488. Here, a much larger pillar is shown on the rise side than on the dip side of the shaft. The vertical lines are shown dotted at *a b* and *a' b'*, and the lines at right angles to the dip are shown dotted at *a c* and *a' c'*. The lines of fracture are shown solid between the dotted lines. On the rise side, the line of fracture approaches the shaft, while on the dip side it goes away from the shaft.

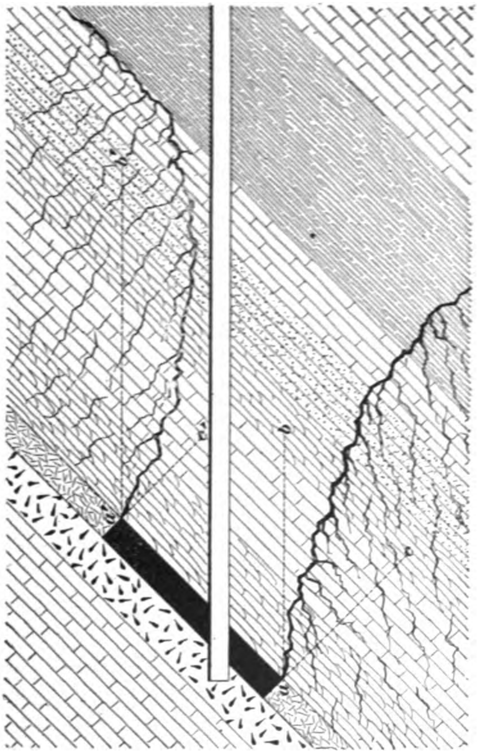


FIG. 488.

There is, perhaps, no point in mining on which so much diversity of opinion exists among authorities as on the size of shaft pillars required under given conditions. Any accident to the shaft caused by a pillar of insufficient size entails great expense and loss of output, and it is better, therefore, to err on the side of safety in this matter.

protect the shaft and the buildings B, the furthest being 100 feet from the center of the shaft.

1577. For shafts deeper than 700 feet, a good formula for determining the approximate size of shaft pillar under average conditions is : radius of shaft pillar $= 3 \times \sqrt{D \times t}$, where $D =$ depth of shaft, and $t =$ thickness of seam. Thus, a shaft 900 feet deep, which is sunk to a seam 8 feet thick, should have a pillar whose radius $= 3 \times \sqrt{900 \times 8} =$ 254.56 ft. When a shaft exceeds 700 feet in depth, it is seldom necessary to provide extra pillar for buildings, unless the seam is extraordinarily thick.

Great care should be exercised in determining the size of shaft pillars in districts where experience has not already determined the best dimensions.

SLOPE PILLARS.

1578. These pillars depend on the five principal points mentioned in speaking of shaft pillars. However, there is not much danger of the draw destroying the slope, because the line of the slope is nearly at right angles to the plane of fracture, whereas in a shaft, the line of the shaft and the plane of fracture converge in pitching seams.

1579. By assuming that a mass of strata receives no support by virtue of its own strength or adhesion to the surrounding strata, which is true over large areas, it may be inferred that pillars will be subject to weights varying directly as their depth from the surface, multiplied by the cosine of the angle of dip. Therefore, pillars should increase in size as the slope advances downwards. What the exact increase should be can not be determined definitely enough to warrant the formation of a rule.

For a close approximation of the size of pillars required at the bottom of a slope, when conditions are normal, the formula $3 \times \sqrt{D \times t}$ (see Art. **1577**) may be used, in which D should represent the *vertical* depth of the slope below the surface, and t the thickness of the seam. The removed as soon as space is made for other longitudinal pieces. This process goes on until a complete lining, consisting of longitudinal bars and cross-struts between them, exists all around the excavation. In heavy ground, the longitudinal pieces are often connected by transverse bars *a*, *a*, Fig. 492. Vertical props *b*, *b* are set between these bars until, at the completion of the work, the appearance is as shown in Fig. 492, where *A* is a cross-section and *B* a longitudinal section on the line *x y*. The masonry is now commenced. A lining of sand is spread in the bottom, and shaped to the curve of the brickwork. A wooden frame or "template," built the exact shape and size of the finished dimensions of the inside of the arch, is fixed at such a height above this sand as will allow the thickness of the brickwork decided upon to be placed between it and the sand. The bottom arch or invert is built first; then the sides are continued until they meet in the center line at the top of the arch.

1588. In most of the shaft bottoms in America, cars are caged from both sides, there being an empty and a loaded track on each side. It is often necessary to pass cars from one side to the other, and because the law (of Pennsylvania) requires a passage around the shaft, the bottom is so arranged. In well-arranged collieries, the caging is all done from one side, and the cars travel in the direction shown by arrows in Fig. 493, the tracks having a down grade in that direction.

Perhaps the most satisfactory arrangement of a shaft bottom, where conditions are favorable, is shown in Fig. 493, in which *P* is a plan and *K* a section of the roads. The method of handling the cars is as follows: A loaded car is taken from the road *a* to the shaft *s* by way of the road *d* or *c*, depending upon which cage is down, and by it the empty car standing on the cage is bumped off and run by gravity to the point *b*, and by virtue of its start it ascends the steep grade *b c* sufficiently far to give it force enough when it reverses to run along the road *b g d* far enough to accommodate a trip of cars. At the point *b*, there is a pair matter. By the arrangement shown in Figs. 493 and 494, the gradients are so arranged that the movement of the loaded and empty cars is almost automatic. When there is more than one deck, this arrangement will only suit when the position of the cage is changed to bring each deck alternately on a level with the shaft bottom. Each change will take nearly as much time as hoisting one car to the surface by a single cage. To overcome the difficulty of changing the position of the cage, the bottom is arranged to suit the decks of the cage, the loaded car being lowered to the deck-level and the empty cars being raised to the level of the seam by an inclined plane or an engine. When there is considerable dip to the seam, if the production from each side is equal, two decks may be used by making the bottoms independent of each other, at levels suiting the *decks* of the cage.

1591. Where endless chain or rope haulage is in use, the cars may be made to pass at will from one landing to the other by simply arranging the chains or ropes to suit the conditions.

PILLARS IN THE MAIN WORKINGS.

SIZE OF PILLARS.

1592. In determining the size of the pillars for the main workings, at least five points are considered:

1. *The Ventilation Required.*—If there is much firedamp or chokedamp given off, or much powder used, the formation of long pillars without cross-cuts necessitates a special and expensive mode of ventilating each working face by carrying a board or canvas brattice from the nearest cross-cut to the face. This enables air to be carried to the face along one side of the brattice, and returned along the other. In some cases where considerable good building material is obtained from the waste, packwalls a few yards wide and built close against the roof take the place of the brattices.

2. *The Nature of the Roof and Bottom.*—Where the roof, or bottom, or both are soft, large pillars and long narrow

1. *The Nature of the Coal.*—Some seams are of such a nature that the sides and corners of pillars chip or split off when the coal is opened up, thus causing considerable waste. This splitting or chipping is due to the disintegrating effect of the atmosphere, or to pressure of gas in the coal, or to the pressure of the roof, or to any two of these causes combined, or to all three. When this chipping or splitting off of pillar coal occurs, pillars of greater area are required.

2. *Nature of Roof and Floor.*—If the floor is soft and the roof hard, small pillars are so squeezed down as to be both troublesome and expensive to remove, and the floor is very liable to "creep." If the floor is hard and the roof brittle, the latter will fall more or less in spite of all efforts, and the expense of "cleaning up" and timbering is heavy. If top and bottom are both strong, the weaker substance—the coal—is crushed, and its value proportionately decreased.

3. *Inclination.*—A very hard roof, such as a sandstone or limestone, will not break down in the ordinary working places, and so all the weight remains on the pillars until their removal begins. Then, although in pitching seams the amount of pressure varies inversely as the inclination, and is less than in flat seams, there is great danger of a rush or movement of the strata over the pillars, when robbing or withdrawal begins, unless they are large in proportion to the openings.

4. *Dislocations.*—These cut up the strata, and when of large size and running in certain directions, necessitate a greater proportion in pillars to withstand the pressure of the dislocated and subsequently loosened roof, when a subsidence is brought on by the removal of the pillars next them. If no attention is paid to dislocations, disastrous "crushes" may ensue, destroying acres of pillar coal.

5. *Depth.*—The depth of the seam is really the measure of the pressure. The aggregate power of resistance of the pillars must not merely sustain this pressure during the first working, but it must have such a surplus, and that so distributed, as to ensure the safe, economical, and entire

extraction of each pillar in turn. A depth may be finally reached when the pressure can not be resisted by pillars of any size, and the pillar method must be abandoned. The limit of depth varies with the nature of the coal, inclination, nature of strata, etc. In the foregoing, the conditions affecting the formation of pillars in the first working of the pillar method (often called working in the "whole") have been considered. It is now in order to treat of the second working, sometimes called the "brokens," which is the removal of the pillars. This requires the exercise of sound judgment and much good practical skill.

PILLAR DRAWING.

1595. Generally speaking, the sooner, consistent with economy, that the pillars are removed the better. In gaseous mines the pillars ought not to be taken out until the workings have reached a considerable distance from the shaft. If the coal is tender, the strength of the pillars should be considerable, and their removal delayed; because, if they are taken out, the probability is that those left for the support of the passages will be destroyed by the pressure, especially if the roof is good. In the case of bad roof, the pillars should be taken out as soon as possible, not only for economy, but also because, when the roof is bad and falls freely in the gobs, the débris soon sustains the superincumbent pressure and relieves the weight on the pillars next the hauling or main roads. Early drawing of pillars also concentrates the working district, and gives greater facilities for keeping up a limited extent of workings, and makes the ventilation more efficient and simple.

1596. In some cases the following conditions must be considered before pillar extraction is started :

1. *Working Contiguous Seams.*—When two or more contiguous seams are worked simultaneously, the removal of the lower pillars may very seriously affect not only the economy but the safety of the operation above. It may, therefore, be better policy to leave the pillars in the lower seam a much longer time than if there was but one seam.

2. *The Character of the Roof.*—If the roof is very strong and the area of pillar drawing is comparatively limited, a very dangerous amount of weight will be thrown on the remaining pillars; or, if the faces are not sufficiently far advanced, the disturbance produced in the strata may extend far enough to injure them.

3. *The Amount of Water that May be Let into the Workings by the Subsidence of the Roof.*—When a water-bearing stratum lies within the probable zone of subsidence, care must be taken not to disturb it.

4. *Surface Damages.*—In some cases, the immediate consequence of drawing the pillars will be the subsidence of the surface, which may result in large claims for damages.

1597. The conditions at collieries are so varied that no rule can be laid down to suit all. The effect of pressure varies with the nature of the roof and floor.

If the roof has fallen in the rooms, the drawing of a pillar can be most advantageously accomplished by taking a skip or slab off one side, advancing from the mouth of the room, and finally taking the remainder on the retreating plan. If, however, the roof is so strong that the entire extraction of a pillar is accomplished without inducing a fall, an enormous weight is thrown on the adjacent pillars. This has a tendency to crush the pillars if the floor is hard, or to force them into the bottom if it is soft.

1598. The order in which pillars are removed is important, as it affects both the safety and economy of the work. In working pillars on a pitch, a lower range should not be commenced till those immediately above are finished. In drawing pillars, their ends should be kept in a *straight* line. If they are not, some pillars are subjected to greater pressure than others, valuable coal is lost, and the work is materially interfered with. When all the pillars are left standing till the boundary is reached, the pillars are best drawn outwards.

1599. There are several ways of drawing pillars. When a pillar is small, it may be removed by one operation, but the standing pillars of some of the weight. *A creep or thrust can not be prevented by any means when it has set in, but it may be confined to a limited area, if caught in time, by reenforcing the pillars as stated above.* The creeping or thrusting will go on until the excavations are filled, and the whole becomes compact enough to resist the weight. This sometimes takes many months, but it is a sure result, be the action fast or slow. Confining a creep or a thrust to a certain limit is a difficult, expensive, and dangerous operation, requiring the utmost skill and care in every individual engaged in the work.

1603. Reopening.—After the subsidence has entirely stopped, the pillars of coal subjected to thrust or creep may be partially recovered by methods adapted to the thickness of the seam. Thin seams can not be opened very readily, and, indeed, unless the coal is very valuable, reopening thin seams seldom pays. The old entries must be reopened by taking up the bottom, or taking down the top rock, which must be stowed in any open place, or taken to the surface, or by driving new entries across the pillars; in any case, much rock must be handled. In thicker seams, say over 6 feet, it is customary to make new roads by skipping the pillars; i. e., by taking a strip off the side of the pillars wide enough to carry a road under new top. In such cases, much timber must be used on the broken side, and where the road is carried across the waste or old excavations. Moreover, a district may again begin to creep or thrust whenever work is renewed on the pillars. In most of the cases tried, in many ways, and under many different circumstances, the operation was very unsatisfactory.

METHODS OF WORKING BITUMINOUS SEAMS.

1604. Fig. 495 shows seven districts worked on the "Pillar and Chamber," "Pillar and Stall," and "Panel" systems, principally in vogue in the bituminous coal fields of the United States. Several methods can frequently be combined to advantage in the same mine.

Most mines in the bituminous regions of the United States are opened up by the **double-entry system.** In this system, the main and butt, or productive, entries are driven in pairs and in definite directions suitable for the most economical and advantageous working of both the rooms and the pillars. The **triple-entry system,** which consists of a main entry or intake in the center and a return air-course on each side, is used either where the seam generates a large amount of gas, or for the purpose of getting out large quantities of coal, particularly when mined by several different systems.

1605. District 1 represents a group of "breasts," "rooms," or "chambers" which are driven about 6 yards wide and 12 yards apart. Narrow cross-cuts, called "breakthroughs," are driven from room to room for ventilation. The heading from which the rooms are turned off is the haulage road, and the other heading is simply an airway. This system is used where the pillars are to be left in for the purpose of preventing any serious settlement of the surface, whereby buildings may be injured or water let into the mine.

1606. District 2 is a group of rooms showing the method generally used where the roof is good and the dip of the seam does not exceed 8 degrees. The rooms are about 8 yards wide and the pillars 6 yards wide. Where the dip is 3 degrees or more, the rooms are turned off to the rise only, the lower heading being used simply as an air-course. There is no road in the air-course, except near the face, the coal being taken out to the principal entry through diagonal cross-cuts at intervals of about 60 yards. When a new diagonal cross-cut is completed, the road is taken up in the one just back of it and is laid down in the one just finished. The rooms are turned off up the pitch, thereby avoiding any hard pull while taking the loaded cars from the face. When the seam pitches less than 3 degrees, butt headings are turned off the main headings, in pairs, at intervals of about 200 yards, and rooms are turned off both butt headings to the employed in developing the panel; in this particular case, the pillar and chamber method is used.

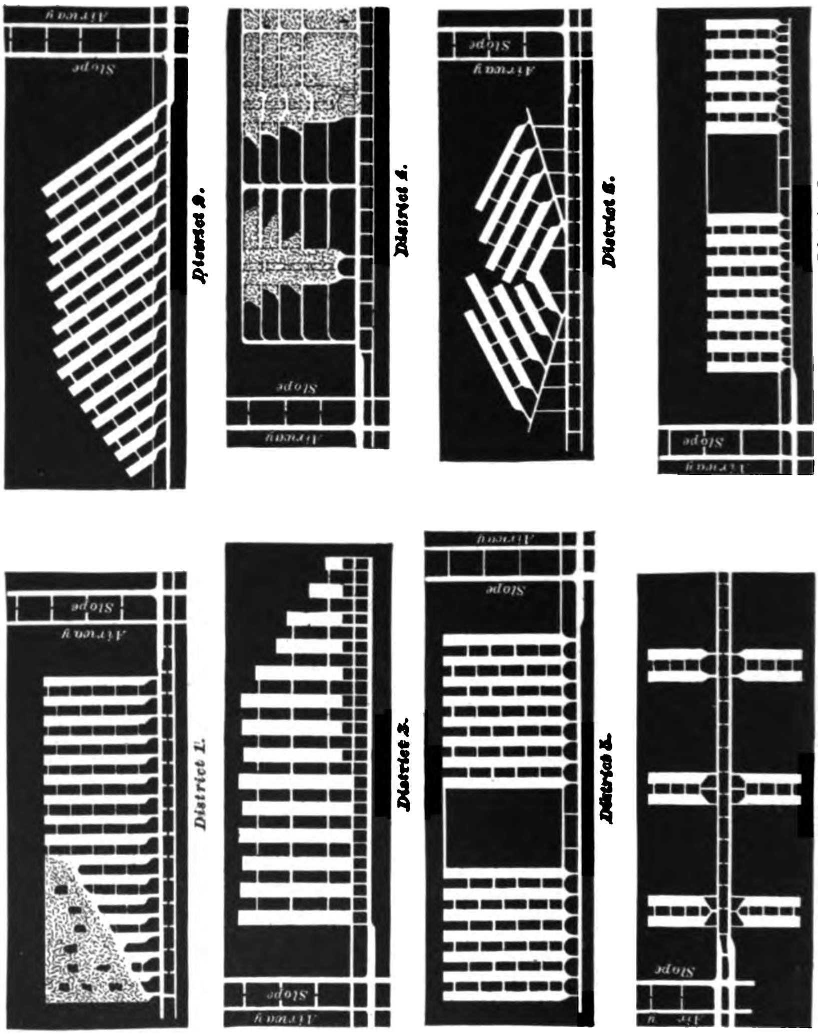


FIG. 406.

1613. It should be remembered that in all these districts the rooms are driven on the "faces," i. e., perpendicular to the face cleats, or as nearly so as possible, because more lump coal can be produced and the bearing in can be more easily effected than by driving them in any other direction.

There are conditions which require that the rooms should be driven at different angles to the face cleats; but these will be fully explained further on and need not be dwelt upon here.

METHODS OF WORKING ANTHRACITE SEAMS.

1614. Fig. 496 represents five different districts of mines in the anthracite coal region of Pennsylvania. These districts show in a general way the arrangement of the necks of the breasts for chutes best suited for particular pitches. This arrangement of the chutes, etc., will be explained in detail further on.

1615. In districts 1 and 2 the seam is nearly flat, and the coal is obtained in chambers varying in width from 20 to 30 feet. The coal is nearly all shot out of the solid, and a great deal is unavoidably lost in drawing back the pillars, the best results in thin seams being scarcely 80 per cent. mined. In district 1 part of the pillars are drawn, while in district 2 the rooms are not yet finished, and are driven obliquely to the level to obtain a moderate grade for haulage. A chain pillar which is parallel to the gangway and air-course is left between the different lifts, as the districts are called when on a pitch. Each of these pillars protects the lift immediately below it and prevents the water from running down into the lower lifts. Part of the chain pillar may be taken out when the lift just below it has reached its limit.

1616. The coal is supposed to have considerable pitch in districts 3 and 4. In district 3 the breasts are opened with two chutes each, and the rooms are 10 to 12 yards wide. In case there is a bottom split of the seam, one split should or coal occur, the men can reach the heading in a very few seconds and be perfectly safe.

It will be noticed that a great deal of narrow work must be done before any great quantity of coal can be produced by this system. The only reason that breasts are driven in pairs and at intervals, as above stated, is to provide means of getting a fair quantity of coal while the narrow work is being done; they are not an essential part of Col. Brown's system. It is claimed that the facility and cheapness with which the coal can be mined, handled, and cleaned in the mine more than counterbalances the extra expense for the narrow work.

1617. In districts 5 and 6 the seam is supposed to have a light pitch. In district 5 is shown a method of opening breasts with a single chute, in the center of which the coal slides on sheet iron. The breasts are worked from 8 to 12 yards wide and in groups of from 8 to 10 breasts. These groups are separated by strong pillars from 150 to 200 feet wide. These pillars are left in to prevent any very heavy crush affecting the gangway and working breasts, and to ensure the breaking of the top rock so as to relieve the pillars of excessive weight. In district 6 the seam is supposed to dip from 10° to 15°. This is not enough dip for chutes and too much for haulage roads on the full rise. Therefore, slant gangways or branch entries are driven off the main entry, and backswitch breasts are turned off them.

1618. In district 7 the gangway is supposed to be driven in the syncline or basin, and rooms are turned off to the right and left. Whichever system of opening the breasts is employed, the best results will be secured by carrying on the work in sections, or panels, having extra strong pillars of coal to support the overlying strata and as far as possible to lessen the crush, which is considerable under such conditions and at so great a depth. In district 8 the pitch is very heavy. Under such conditions it is advisable center, which ends in a platform projecting into the gangway, off which the coal can be readily loaded into the mine car. When this method is employed, the refuse is thrown to either side of the chute. If the pillars are to be robbed by skipping or slabbing one rib only, it is well to keep most of the refuse on one side. Sometimes, when the top is good, and the breasts are driven wide, two chutes are used, but the cost of making the second chute is considerable and is, therefore, not advisable unless necessitated by the method of ventilation employed.

1628. Fig. 498. In the plan *A* the roof is supposed to be removed from the coal and the reader looking down upon the breast. The section *B* is laid along the lines *h e* and *d b*.

The figure shows a method of opening a breast by two chutes *c*, *c*, when there is a great amount of refuse, or when a great amount of gas is given off. The chutes are extended, as the figure shows, up along the rib to within a few

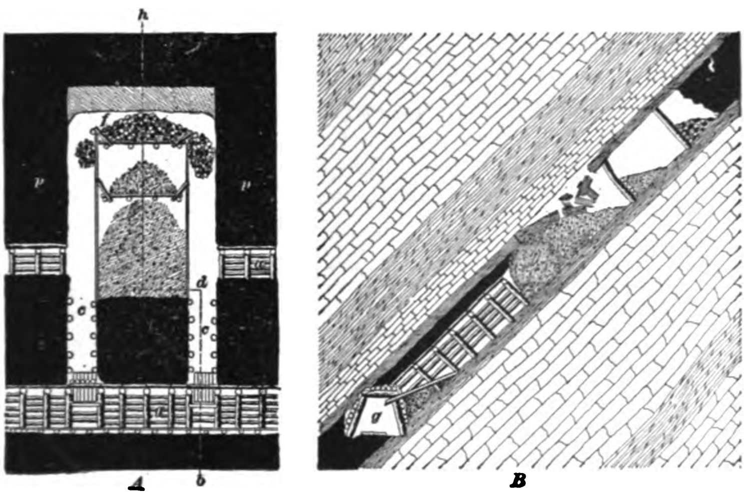


FIG. 498.

feet of the working face, either by planking carried on upright posts, or by building a jugular manway, so named because it is built of **jugulars** or inclined props, faced by forming the manways *b*, *b*. The refuse *g*, in these cases, only partially fills the gob.

1631. In working very thick seams on heavy dips, where there is not enough refuse to fill the middle of the breast, the miner has nothing to stand on, the platform

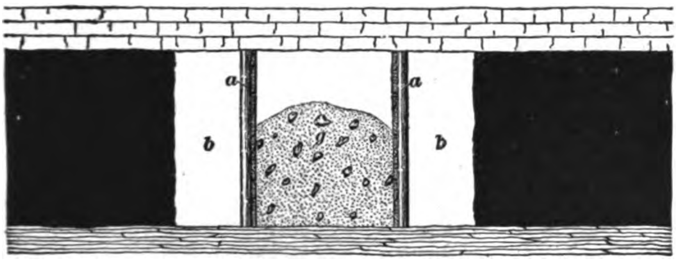


FIG. 500.

being impracticable; therefore, it is necessary to leave the loose coal in the breast, which involves the use of an entirely different mode of opening. Loose coal occupies from 50% to 90% more space than coal in the solid; therefore, when the coal is left in the middle of the breast, means must be supplied to draw off the surplus.

This surplus may be drawn out through a central chute with best results, because the movement takes place principally in the coal lying near the center of the breast. If the roof is poor, the movement of the coal will not in this way cause it to fall and mix with the coal; and, if the floor is soft, the jugulars, which are stepped into the floor, are not so liable to be unseated, closing the manway and blocking the ventilation. The surplus is sometimes sent down the manways, leaving the loose coal in the center of the breast undisturbed until the limit is reached.

1632. To prevent the coal from running out through the chutes, the opening into the breast is closed by a battery constructed by laying three, four, or five heavy logs across the openings, as shown at *b*, Fig. 501, or built on props as shown at *b*, Fig. 502; a hole is left in the center, or at one side of the battery, through which the coal may be drawn. The battery closes all of the openings into the breast, except the space occupied by the jugular manways, and is made air-tight, or as nearly so as possible, by a covering of plank.

1633. Fig. 501 is a plan and section of a breast opened

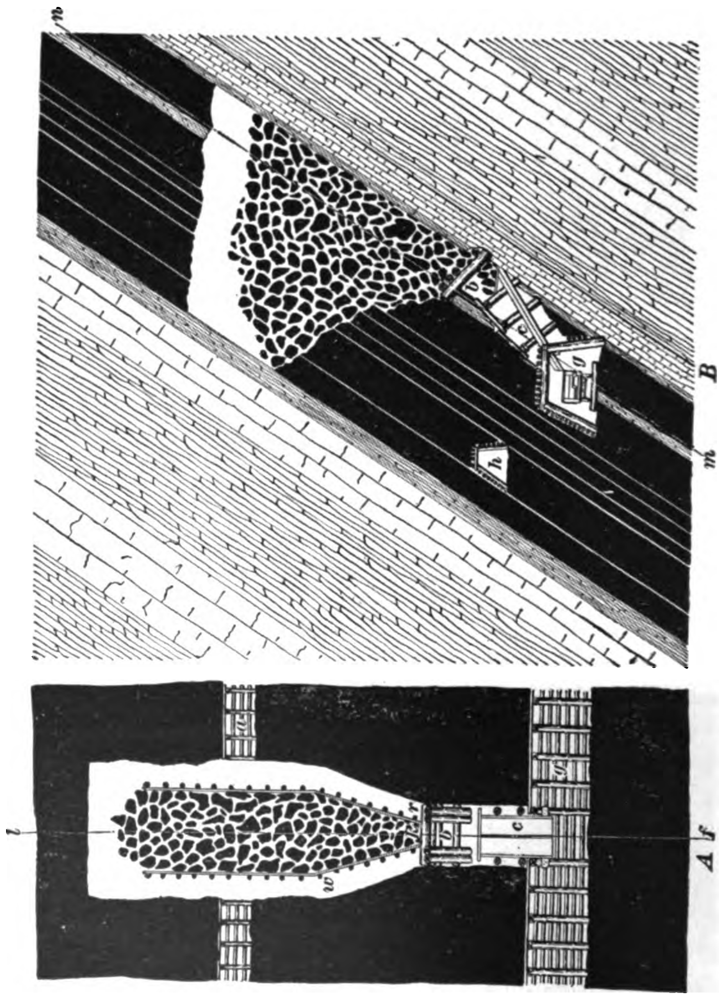


FIG. 501.

up by a single chute. The plan *A* is taken on the line *m n* shown on the section *B*, which section is taken on the line *f l* shown on the plan *A*. The pitch is great and the seam is so thick that the breast must be kept full of loose coal for the men to work upon, the surplus being drawn off at the battery *b* and run into the car standing on the gangway *g* through the chute *c*. A manway *w* is made along each side of the breast, for the purpose of ventilation and affording a passage for the men to reach the working face. The heading *a* is used for an aircourse between breasts. The main airway *h* is driven over the gangway *g*, where it will be well protected.

By drawing the surplus coal through a central chute, the manways are not injured so much as when it is drawn off through side chutes, as the coal will move principally along the middle of the breast. When the breast is worked up to its limit, all the loose coal is run out of the breast and the drawing back of the pillars is commenced, unless for some purpose they are allowed to stand for a time.

1634. Fig. 502 shows a plan *A* and section *B* of double-chute breasts used in very thick seams having a heavy dip. The section *B* is made along the line *p q* on the plan *A*, and the plan *A* is made along the lines *r s* and *s t* on the section *B*. The breasts are entered by two main coal chutes *c*, *c*, each of which is provided with a battery *b*, through which the coal is drawn. A manway chute *m* is driven up through the middle of the pillar for a few yards, and is then branched in both directions until each branch (slant chute) intersects the foot of a breast near the battery *b*, as shown in the figure. The jugular manways *n*, *n* are started at this point and continued up each side of the breast. The main airway *h* is driven in the solid, through the stump *A* above the gangway.

1635. The figure also shows the main gangway *g* driven against the roof. By driving the main gangway against the roof, where the pitch is heavy, the loading chute *c* is more readily controlled, because the pitch of the chute is lessened.

When the main gangway is not driven against the roof, a gate is placed in the chute below the check-battery, which gradually widened out to the proper width on both sides, as shown in the figure. The section is made on the lines *l k* and *i j*, and the plan is made through the lines *p q*, and therefore does not show the headings *c* and *d*. In the middle of each stump a small manway chute *m* is driven up a few yards, and then branches *s*, *s* are turned off in both directions until intersection is made with each breast. From the top of these manway-chutes, manways *w*, *w* are carried up on each side of the breast, as in other plans. It will be

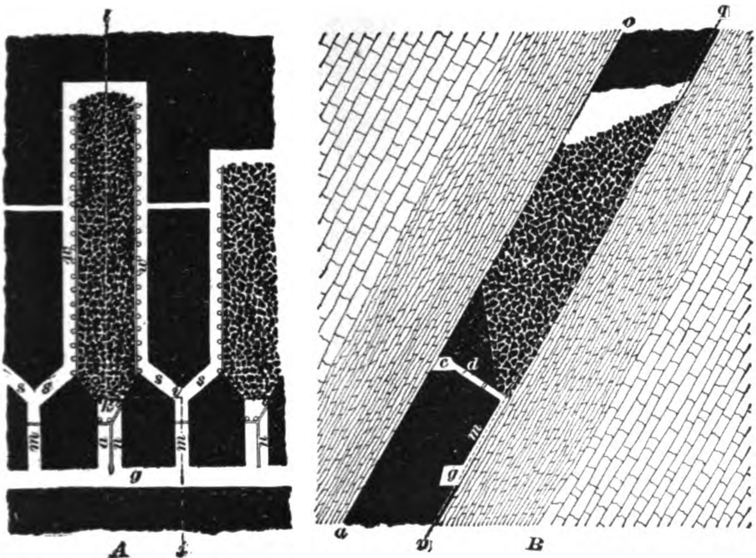


FIG. 504.

noticed in this case that the main chute *a* and battery have no connection with the slant and manway chutes *m*.

A narrow manway *n* is usually made by planking off a portion of the main chute so that the loader may have free access to the battery at all times.

When the pitch exceeds 50°, the gangway is sometimes driven in the top bench of the coal, which lessens the risk from a squeeze, and the chutes may be driven at an angle on which the coal will be most easily controlled.

This plan, however, is not frequently adopted, because it below. The pillar separating *A* and *B* will be worked away much in the same way. The pillar between *B* and *C* is shown as being taken out in a different way. A narrow chute or heading is driven right up the middle of it and cross-cuts put in right and left a few yards from the upper end. Into the middle of each square block of solid coal so formed, shots are put in as indicated by the white lines, and all fired

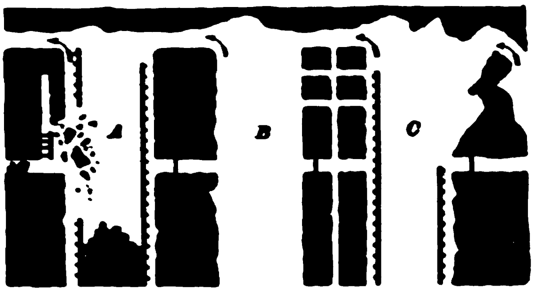


FIG. 507.

simultaneously by a battery. The operation is repeated in each descending portion of the pillar, unless, as sometimes happens (especially in very jointy or free seams), the pillar starts to run, which even a breast will often do under favorable conditions, so that scarcely any *mining* need be done after the gangways are driven, and the chutes started, and "batteries" formed. A case of the coal running of its own accord is sketched on the right of *C*.

ROCK-CHUTE AND TUNNEL MINING.

1643. Fig. 508 shows a section of two seams, separated by a few yards of rock, and worked on what is known as **rock-chute mining.** Chutes, from 4½ to 7 feet high and 7 to 12 feet wide, are driven in the rock from the gangway or level *g* to the level *l* in the seam above, at such an angle that the coal will gravitate from the upper seam into the gangway *g* driven in the lower seam. The working, otherwise, is similar to that previously described.

1644. Vol. AC of the Geological Survey of Pennsylvania says *rock-chute mining* contemplates a sequence of operation which may be summarized thus:

1. The opening of all gangways and airways in the lower seam, to develop coal as yet untouched, in a thick seam lying a few feet above it.

2. Developing the thick bed by a regular series of *rock chutes* driven from the gangway below; workings being opened out from chutes as in ordinary pillar and breast working—the panel system or some other plan may be found better than pillar and breast workings.

3. Driving the breasts to the limit of the lift and robbing

FIG. 508.

out the pillars from a group of breasts as soon as possible, even if a localized crush is induced.

4. After one group of breasts is taken out and the roof has settled, opening a second series of chutes for the recovery of coal from any large pillars that were not taken out when the crush closed the workings.

5. While the work of recoveringthe pillar coal is in progress, a second group of breasts may be worked, and the process continued until all the area to be worked from that gangway has been exhausted. The same process is employed in opening lower lifts.

In the upper and thicker seam, when the coal is very hard, a breast *b* is worked to the limit and the loose coal nearly all run out through the chute *s* into the gangway *g*. The "monkey gangway" *m* is driven near the top as a return airway, and is connected to the upper end of the

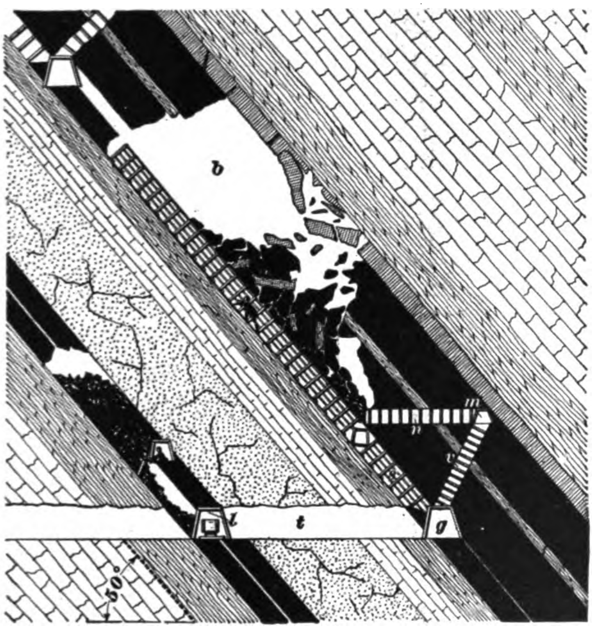


FIG. 509.

chute *s* by a level heading *n*, and to the main gangway *g* by a heading *v*. These headings are driven for the purpose of ventilation and to provide access to the battery in case the chute *s* should be closed. In the lower seam the breast is still being worked upwards in the ordinary manner.

WORKING CONTIGUOUS SEAMS.

1647. Fig. 510 shows the method of working twin seams separated by a few feet of slate or rock. This probably suggested the rock-chute method shown in Fig. 508.

To the right of the figure, the seams are quite flat and are worked by running the car *c* from the level *l* into the water or gas, and plugs should be kept handy, to stop up the holes in case water or gas is struck. Only safety lamps should be used at the face. In no case should more than one opening be driven towards old workings containing water or gas. In pitching seams, when the relative elevations of both the old workings and the new are approximately known, flank bore holes are necessary on one side only. When the seam has a very heavy pitch and the coal is free, much longer holes are necessary to ensure safety.

PROPPING.

POSITION OF PROPS.

1654. The tendency of the roof is to fall in the direction of the force of gravity, in the line *b g* (Fig. 512). But where the roof is solid and holds together, like that in

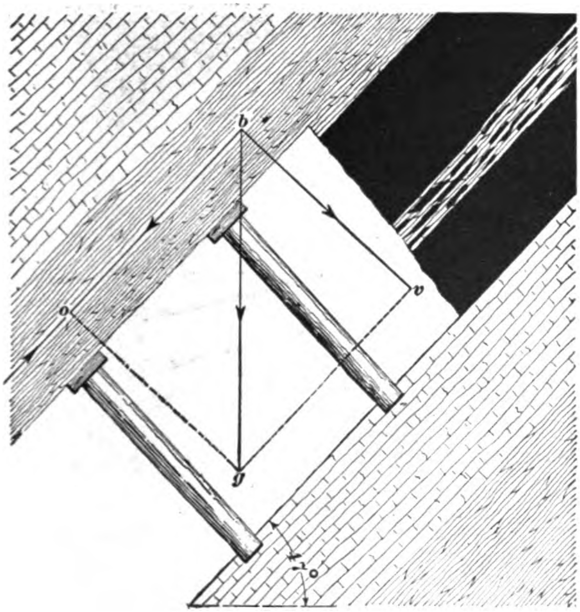


FIG. 512.

Fig. 512, this force of gravitation, represented by line *b g*, is resolved into two forces, represented by the line *b o*, parallel to the dip of the seam, and the line *b v*, at right angles

1656. The following table shows the maximum and minimum angles at which props should be set on varying inclinations :

Dip of Seam.	*Underset at Prop.	
	Minimum.	Maximum.
6°	0°	1°
12°	0°	2°
18°	1°	3°
24°	1°	4°
30°	2°	5°
36°	2°	6°
42°	2°	7°
48°	3°	8°
54° and upwards.	3°	9°

* Underset means that the head of the prop leans up the pitch, and the angles given show the deflection from a line at right angles to the floor.

SETTING PROPS.

1657. Props in some districts are invariably set with the thick end upwards. In respect to efficiency, one end is as well upwards as the other, as resistance equals pressure, and the strength of the post corresponds to its thinnest sectional area. By placing the thinnest end of posts in the floor, a smaller foot-hole is required, which will consequently take less time to cut out. Being more solid and stronger at their thick ends, props, when being set, are better able to bear the blows on their head when set with the thick end upwards. Some managers set the thick end down, while others set the larger end against the weakest stratum, be it top or bottom.

1658. Props for thick seams are usually rounded at the bottom to fit the foot-hole cut in the floor. Props are rounded in heaving bottoms to prevent their "mopping," i. e., being splintered at the bottom.

very crooked and undesirable road for the application, in the future, of mechanical haulage, although it may be advantageous for the limited use of mule haulage. The application of mechanical haulage should be considered when making a new opening. This would imply that all haulage roads should be as straight as possible, care being taken to avoid even small curves. In many mines the headings are driven on line. "Sights," or plugs with nails in them, from which plumb lines are hung, are placed in line in the roof, near one side, so that the passage of mine cars does not interfere with them.

The grade of the haulage road should be kept uniform throughout by cutting through small irregularities in top and bottom. The little expense incurred will be amply rewarded by the smoothness and rapidity of the haulage of the coal. Where the seam is flat, there may be a great many irregularities, such as local swamps, faults, etc., which render it out of the question to maintain a regular grade throughout. In such cases, the grade should be made uniform between certain points. A road may, in some mines, have many different grades which will not be very objectionable if the road is straight—only a few pounds more of steam are involved, if mechanical haulage is used. Crooked roads soon wear out ropes or chains. In some coal mines where large quantities of gas are given off, large airways—gangways, levels, headings, entries, aircourses, etc. —are required. With a weak top these are best secured by increasing the height, but in case of a strong top, extra width may be taken from the sides.

TIMBERING LEVELS.

1662. In flat seams, the manner of timbering entries, etc., is pretty much as described for drifts, while in pitching seams, different forms of timbering are resorted to. Much depends upon the angle of dip and the thickness of the seam. Round timber, being so much stronger and requiring less preparation for use than square timber, is generally used in timbering levels. The timber used in

In some cases both legs can be dispensed with. Whether the collar *c* can be used alone or one end of it supported by a leg *l* can be determined by the relative cost of forming the holes in the top of the seam, so as to get the collar in place, and of setting and supplying the leg.

1669. Fig. 520 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

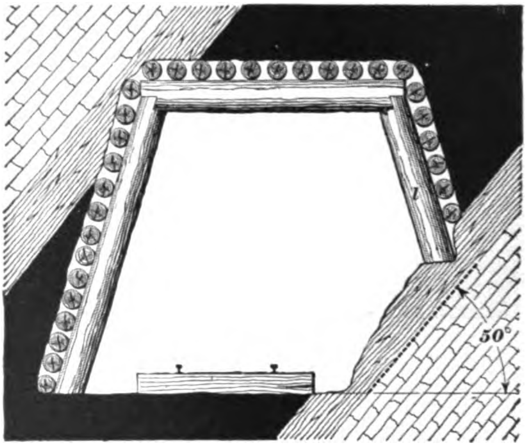


FIG. 520.

method very much reduces 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. The set of timber resembles that of Fig. 518.

1670. Fig. 521 shows a form of timbering used in pitching seams where the coal is soft, and falls to a height greater than that required for the gangway. The leg *l* on the high side is made long enough to reach up to the roof to support the laggings *a*, *a*, which keep 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.

1671. Fig. 522 shows a method of timbering a level when the conditions are nearly similar to those in Fig. 520.

The inclination, however, is greater, and the top and bottom harder. The leg *l* is given a good hold in the bottom so that it will not be pushed out by the pressure of the coal.

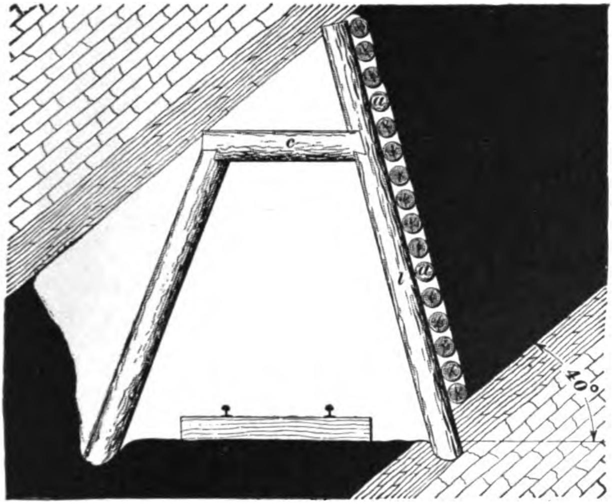


Fig. 521.

It will be observed that in this case the pitch is so great that the bottom on the high side is not disturbed, and the

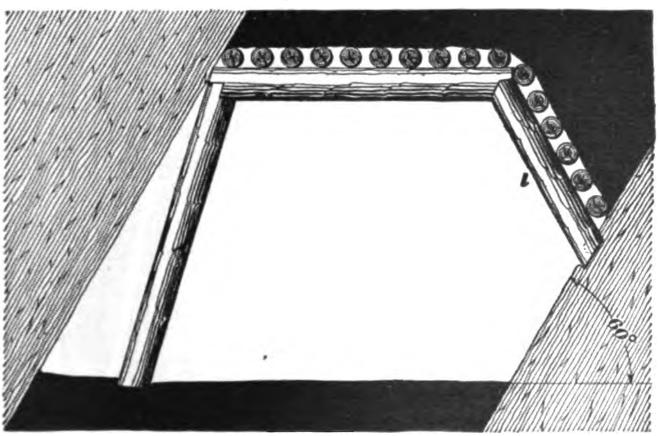


Fig. 522.

coal on the low side is allowed to fall away from the roof, as in Fig. 521.

1672. When the side pressure is great, the power of

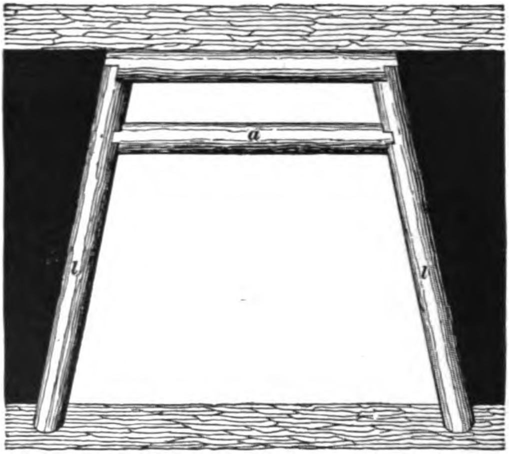


FIG. 523.

resistance is much increased by placing a second horizontal piece *a* between the two legs *l*, *l*, as shown in Fig. 523. This

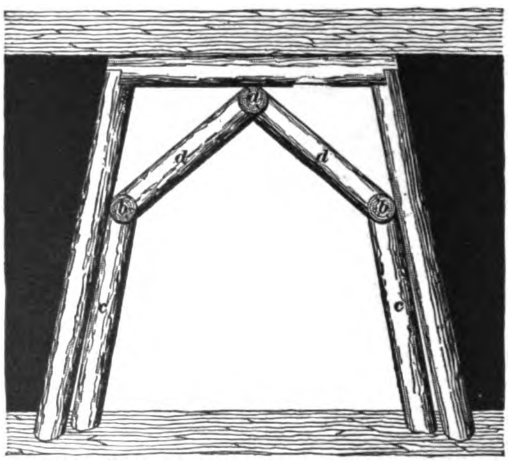


FIG. 524.

prevents the lateral pressure from splitting the legs at their upper ends.

and either derail the car or cause it to run in 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; similarly, the point *a* should be higher than the rail *d*, so that the tread of the wheel will not strike the rail *d* while the car is running along the straight road in the direction from *f* to *a*. The rail *c* being lower than the rail *a*, it is obvious that when a car is to be taken in the switch, the driver will have to push the car towards 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*.

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.

1680. In laying a switch great care should be taken regarding the relative heights of the lead and follower rails. Where the switch is laid to the dip side of the heading, and the loaded cars must be pulled from the dip over the switch, the follower or inside rail should be the higher; while in the case where the switch is laid to the rise side of the heading and the loaded cars will run over it, the lead rail should be the higher.

1681. When the switch is not to be in constant use, a latch *c*, Fig. 529, is used instead of a frog. The switch shown in Fig. 529 is open to the charge of making a broken main road, but it is not liable to derail loaded cars, as the latches will be adjusted by the cars when traveling outwards, if the speed is not great. When this form of switch is used for a turnout, the lead rail *a* is made about double the length of that used for a room. The length of the lead rail is determined in all cases by the radius of the curve where the switch is to be laid.

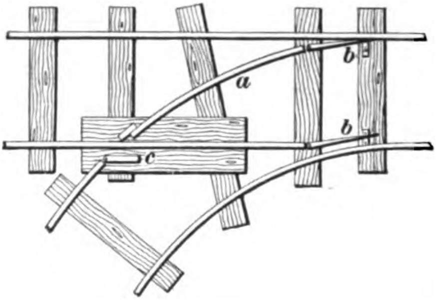


FIG. 529.

The tongues *b*, *b* are sometimes connected by a rod attached to a lever, so that they may both be moved at once from the side of the track, or by a person stationed some distance away. Where the traffic is all in one direction, as in turnouts, the tongues are kept in one position by a spring-pole spiked alongside of the track.

1682. Fig. 530 shows a double switch sometimes used in some parts of the anthracite coal fields of Pennsylvania.

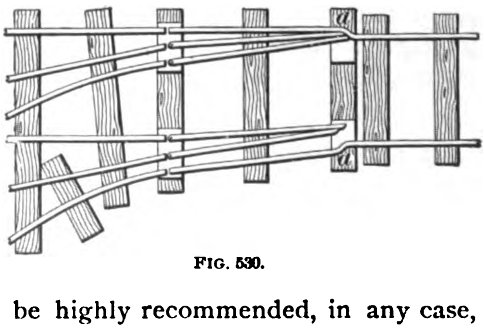


FIG. 530.

It can not be highly recommended, in any case, for inside switches. The short curves or "kinks" in the rails at the points *a*, *a* will derail the cars while passing outwards, if they are running at a high speed.

1683. Fig. 531 shows a rough and ready 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 arrange-

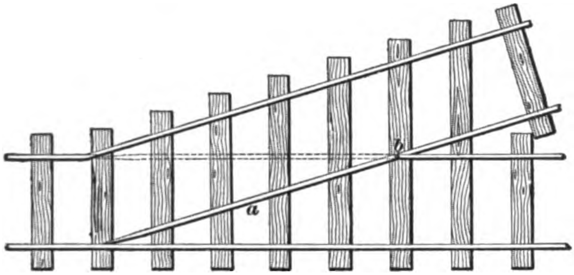


FIG. 531.

ment acts admirably. The dotted line shows the position of the rail *a* when the straight road is in use.

1684. Fig. 532 shows an excellent switch for permanent tracks in coal mines. No frog or latch is required. By

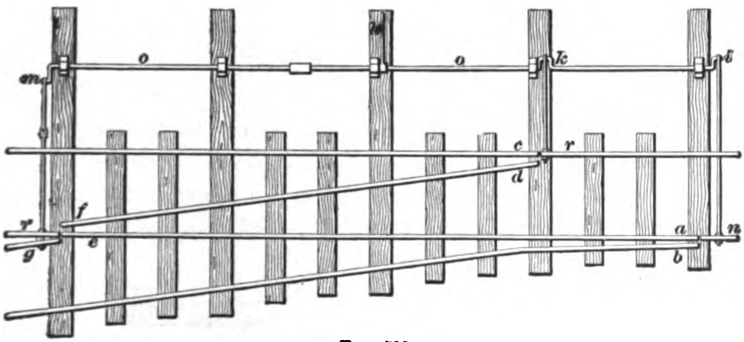


FIG. 532.

throwing over the lever *h*, the throw-rod *o* moves the throws *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 in proportion, the switch gives excellent results. It should not be made of less than 20-pound rail, and heavier will suit better. By this device, it is seen that no frog is needed, and the joints are broken, i. e., they do not occur opposite each other, or on the same tie.

1685. Fig. 533 shows the ordinary stub switch, much used in coal mines. When the lever *l* is thrown over, the

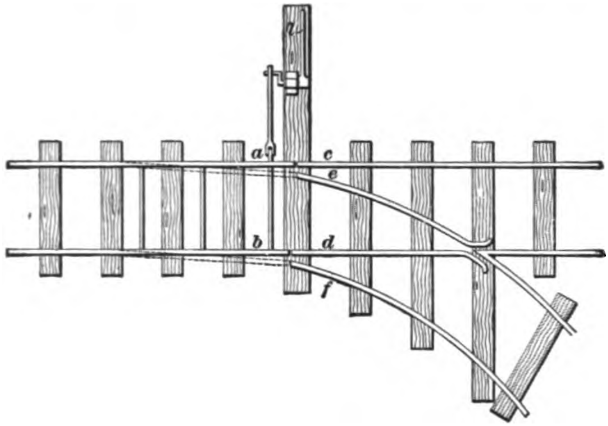


FIG. 533.

rails *a*, *b*, now facing *c*, *d*, are made to face rails *e*, *f*, as shown by dotted lines.

1686. When two tracks cross each other at any angle the same arrangement is used in mines as in railroads. They are called **grade crossings.** Fig. 534 shows a form which is self-explanatory. The cars must pass over this crossing slowly because the roads are broken.

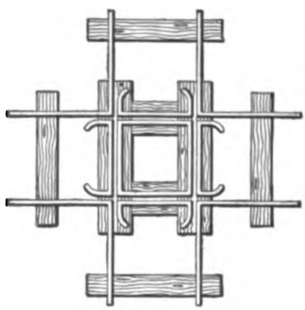


FIG. 534.

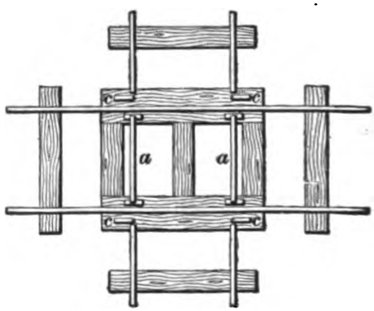


FIG. 535.

1687. When a subordinate road crosses a main road, along which the cars pass rapidly, the main road is left unbroken and the subordinate road is built the height of the rail higher than the main road, and a crossing like that shown in Fig. 535 is used. The cross latches *c* are sometimes held in place by blocks placed at the ends of the short rails inside the main track, as shown at the end of the rail *a*, Fig. 529. However, it is best to hold the latches in place by an iron plate having a shallow groove and placed at each end of the short rails *a*, *a*, so that, in case of neglect to take the latches off the main track, the cars going either way along the main track will remove them and prevent the trip from being derailed.

1688. Fig. 536 shows a convenient switch arrangement for the foot of inclined planes. A uniform grade is continued down to point *A*, and from that towards *B* the grade is just sufficient to cause the cars to clear the switch. In the loaded track *D* the grade is such that the full cars will gravitate from the point *D* to the point *A*. The movable rails *a*, *a* are bound together at each end by clamp-rods or spreaders, or bridles, and securely fastened in the center so

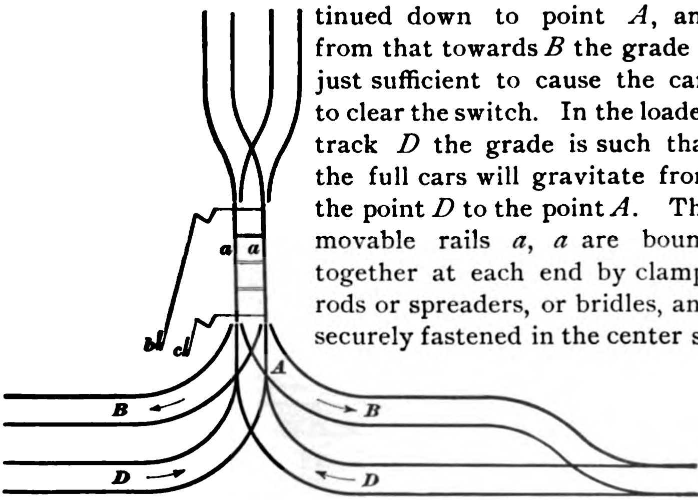


FIG. 536.

that they can not slip longitudinally. By using levers *b* and *c*, the rails *a*, *a* are adjusted to suit the road on which the trip is to travel. Care must be taken not to make the mistake of sending the trip upwards on the same track on which the down trip is descending.

1689. Fig. 537 shows a plan *A* and a profile *B* of a method of connecting the roads of a level, or gangway, to the road in the slope. At a distance of forty to fifty feet above the landing, or gangway *g*, the slope *s* is widened out moderate thickness without taking down a large amount of the top. By this method the cars can be handled on the landing by gravity.

1690. Fig. 538 shows an excellent method of laying switches in either thick or thin seams where the pitch does not exceed 20°. When there is only one track in the slope and coal is hoisted from both sides, the same arrangement is used on each side; but to avoid complications, such as crossings, etc., it is best to have one landing or lift just the length of the switch on the main track further down the slope, as indicated by the dotted lines. The loaded track *l* and the empty track *e* join before they strike the track *s* in the slope.

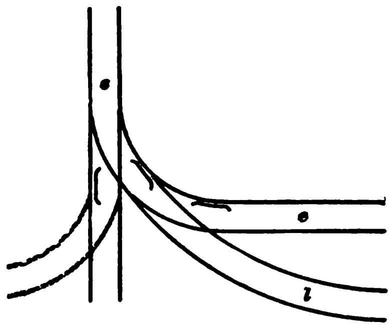


FIG. 538.

1691. Fig. 539 shows a plan *A* and profile *B* of a switch

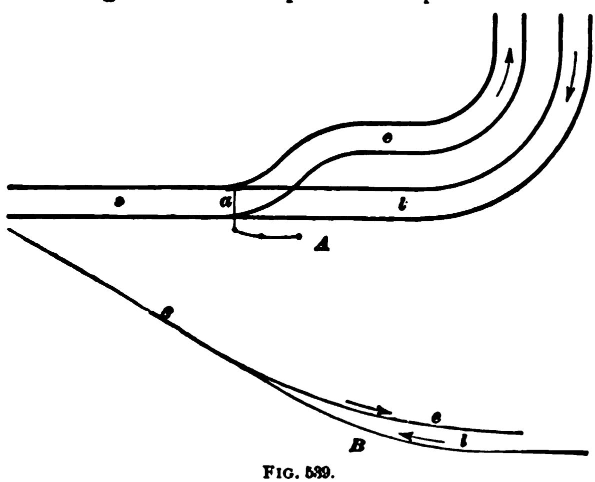


FIG. 539.

used at the bottom of a slope. The figure shows one side only of the slope, the other side being similar. At the junction *a* of the two roads there is a pair of spring-latches, causing the empty cars as they descend the slope to take the road *e*. The empty cars pull the rope in to where it can be attached to the loaded cars which are standing near the slope on the road *l*.

1692. Fig. 540 shows a plan of the switches at the bottom of a slope in which double tracks are used. The two tracks in the slope *s* unite at the point *p* where there are

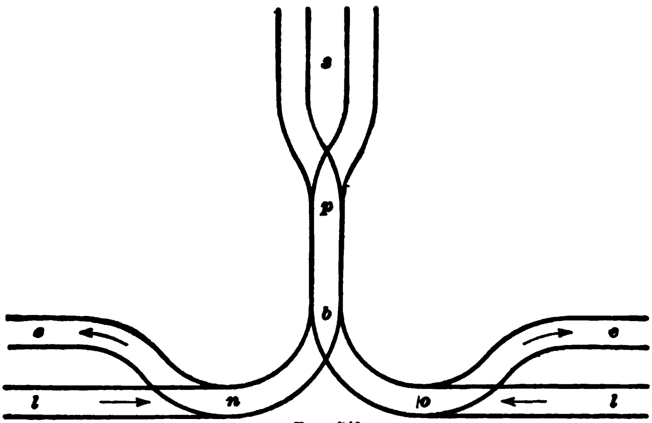


FIG. 540.

latches set by the cars; then at the point *b* two roads branch off, one to the right and the other to the left; and, finally, at the points *n* and *o*, empty tracks *e*, *e* branch off the loaded tracks *l*, *l*. The latches at the point *b* must be set by hand, while those at the points *n* and *o* may be spring-latches. The descending empty trip should have sufficient momentum when it reaches the bottom to run along the road *e* far enough to clear the track for the loaded cars standing on the track *l*.

1693. Fig. 541 shows a plan by which the switches at the bottom can be so arranged and graded that the cars can be handled by gravity. At the points *a*, *b* spring-latches may be placed; while at *p* the latches must be set by a lever, for the loaded cars coming from either of the loaded tracks *l*, *l* must be sent up the road *a* or *b*, depending upon which the empty cars last descended. The latches at *j* are set by the cars which pass over them only one way. It will be observed by examining the figure that the empty cars must take the empty track *e* on that particular side on which they are descending. This requires that an equal number of

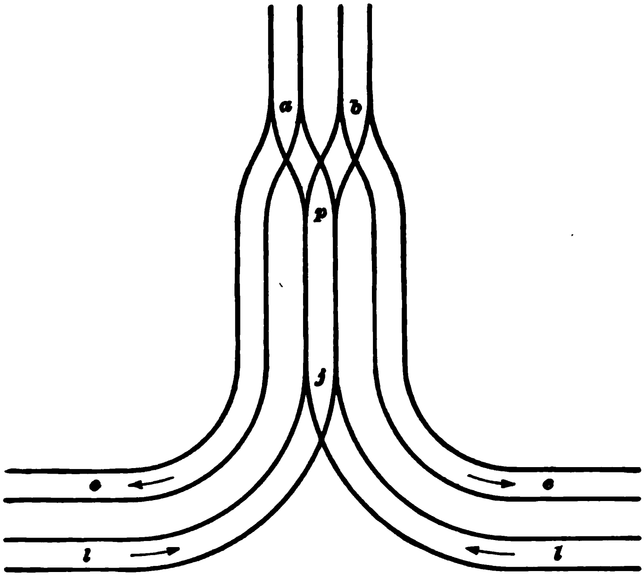


FIG. 541.

loaded cars are supplied by each side. Sometimes the loaded tracks *l*, *l* are connected by a straight track across the bottom of the slope, for the purpose of transferring cars from one side to the other in case one side does not furnish as much coal as the other. Although this plan requires width at the bottom of the slope for but three tracks, it necessitates an extra curve in the loaded tracks, which is an objectionable feature.

1694. The arrangement of the tracks on a slope should be such that there will be as few switches as possible on the slope itself; that the track will be unbroken; that there will be nothing standing at the bottom in line with the tracks in the slope; and that the cars can be handled at the bottom by gravity. The arrangement of the tracks at the top of the slope is often similar to the bottom arrangement. It is always best, however, where there are two roads on the slope, to carry them over the knuckle instead of joining them, as is sometimes done, before they reach the knuckle and beyond which there are again two roads.

1695. When the pitch of the slope is so great that the coal falls out of the cars, a **gunboat** or a **slope-carriage** is used. The former is a special car into which the coal from the mine cars is dumped at the different landings along the slope and conveyed to the surface; and the latter is a car so constructed that, when it is placed on the slope, its top or floor will be horizontal. There is a track on the floor of the slope-carriage upon which the mine car is run. When the slope-carriage stops directly in front of a level, the empty car is taken off and a loaded one put on.

When more than one car is raised at a time, the slope-carriage has no track on it, but is covered with smooth plate iron. The landing is also laid with smooth plates. By this arrangement, with an empty and loaded track in the landing, 2, 3, 4, 5, or 6 cars are run on to the carriage without necessitating any movement up or down. The plate iron enables the cager to run the loaded car on at the upper end of the carriage and then slip it down to the end or against the next car, as the case may be.

1696. Fig. 542 shows the track arrangement of a shaft bottom where the cars are caged from both sides of the shaft. The loaded tracks *l*, *l* have a grade towards the shaft of from 1 to 3 per cent., depending upon the size of car and wheel used, while the empty tracks *e*, *e* are similarly graded in the opposite direction. When both sides of the shaft produce the same number of cars, the operation of caging is very much facilitated by the loaded car on the one side bumping the empty car off the cage on to the empty track on the other side; while, in the case of unequal production on the different sides of the shaft, the bottom man is frequently required to pull the empty car off the cage by hand to the side from which the loaded car is run on to the cage. In the these joints must, moreover, be well calked to prevent the passage of water. It is also especially necessary to make the junction between the dam and the sides, roof, and floor of the passage in such a manner that the water can not force its way through it. To render the dam capable of resisting the pressure that may subsequently be brought to bear upon it, it must be constructed of strong materials, and these must be so disposed as to offer sufficient resistance without becoming deformed. It must be borne in mind in designing and erecting dams that the pressure to be resisted is usually very great, necessitating the best of materials and workmanship.

1700. Dams are used in mines principally for the four following purposes:

1. To keep back surface water.

2. To keep back the water from old workings or from an adjoining mine.

3. To flood a portion of a mine in case of a mine fire.

4. To keep back the deleterious gases given off by old workings.

LOCATION OF DAMS.

1701. A dam should be located in such a place as will secure all the following important advantages, or as many of them as possible:

1. The site chosen should be under a good strong roof and should have a solid rock bottom.

2. The pillars against which the dam abuts should be solid, and of such size as will provide sufficient lateral strength.

3. The dam should be located in a place where the strata will not be disturbed by subsequent mining.

4. It should be located at a place where the opening in the seam is as narrow as possible.

5. It should be located at an accessible place.

from the bottom, for the purpose of allowing the ingress and egress of the workmen during the insertion and wedging of the dam, and a third *c*, which should be from 3 to 6 inches in diameter, and placed near the top. A good, tight valve should be placed on its outer end. This pipe can be used as an air vent while the water is rising. If at any time it is desired to draw the water off slowly, the valve can be opened.

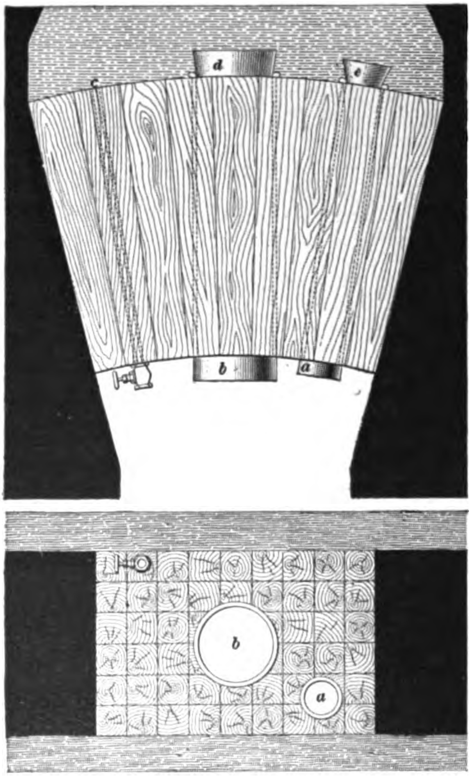


FIG. 545.

The sides, top, and bottom of the seat of the dam should be lined with tarred flannel, so as to ensure a water-tight joint on all sides. After the tapered timbers have been placed in proper position, the wedging is commenced on the inside with wedges 12 inches long and 3″ × 1″ at their heads. After these have been driven in at all the joints, and around the pipes, other wedges are driven in, of diminished size, as long as they can be entered, after which a chisel is used to prepare places for their insertion. The wedges must be perfectly dry. After the wedging is finished, the workmen drive the plug into the pipe *a* through which the water has been flowing. They then pass out through the pipe *b*, drawing after them the plug to close it, which has been placed conveniently for so doing, and the work is completed. A dam of this description, 6′ × 6′ and from 6 to 8 feet thick, will resist a pressure of water of from 130 to 260 pounds per square inch. When the pressure is less, the dam may be made proportionately of less thickness, although under any circumstances rendering a wedge-shaped dam necessary, it would not be advisable to put in one less than 3 feet in thickness.

1707. Fig. 546 shows a sectional plan of a spherical dam built of brick and suitable for places where the coal, top, and bottom are hard. This dam is constructed of three concentric spherical arches dovetailed into the surrounding strata in such a manner that the elevation in a vertical section would have the same appearance as the plan which is shown, except that rock would be shown where the coal is shown on the plan. The object of forming a dovetail abutment is for the purpose of securing good support for the several arches of which the dam is composed, while at the same time cutting away as little of the surrounding strata as possible. The dam is 15 feet thick from *a* to *b* and has a maximum radius of about 30 feet. The arcs *g h*, *e f*, *c d* mark the spherical surfaces of the different arches which go furthest into the surrounding strata.

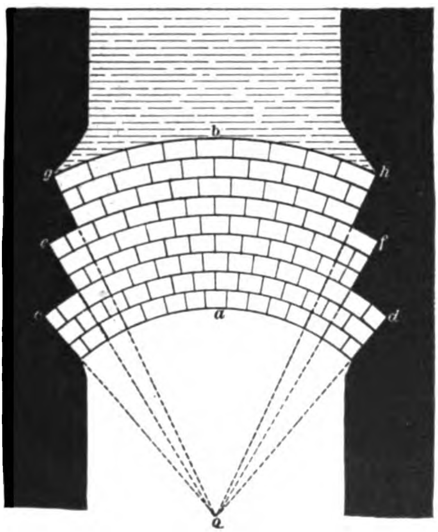


Fig. 546.

The radius of curvature of the arches of brick or masonry dams will depend upon the amount of pressure to be resisted and the size of the opening to be closed. For heavy

1717. Direction of Working Face.—The faces may advance :

1. Perpendicularly to the cleavage planes or **cleats,** or "on the face."

2. Parallel to the cleats, or "on the ends."

3. Obliquely, or at an angle of 45° with the cleats, or "half on."

4. Obliquely between the angles of 1° and 45° from the cleats, or "short horn."

5. Obliquely between the angles of 45° and 90° from the cleats, or "long horn."

It must not be supposed that it is a matter of indifference which of these directions should be adopted in any given case. It depends on the breaking down of the coal, the physical condition of the coal after it has been broken down, and, in some cases, where the cleat of the roof runs parallel with the cleat of the coal, the safety of the workmen. Therefore, it is very important that the circumstances of the case be considered when laying out the workings of a colliery.

1718. The object of all methods and expedients adopted in mining are to obtain the greatest quantity of coal, in the best condition, at the least cost. Since the direction of the face affects the physical condition of the coal, the labor of breaking it down, and the safety of the miner, it is obvious that it bears directly on the cost of production. Two of the principal aims are to reduce the amount of slack to a minimum and to reduce the amount of labor. These are frequently antagonistic, and when this is the case a middle course must be taken.

1719. By working a seam directly on the face the coal may be mined at a minimum price, while the waste or slack may be at the maximum by the weight breaking the coal off when the "backs" (cleats) are close together.

Slack (except in the best coking coals) is comparatively worthless; therefore, the profit must be made entirely from the nut and lump coal. It is, therefore, apparent that it is better to mine the coal in a direction that will increase the ratio of lump, even if the cost of labor be increased.

1720. Coal divides readily along the planes of cleavage, known as cleats, and when some of these cleavage planes are but slightly developed, the coal offers great resistance, comparatively speaking, in a direction perpendicular to the cleat. As longwall workings advance, the roof bends along the line of wall faces and finally breaks, falling into the gob. Two forces are brought into action by this bending: the one which acts downwards tending to crush the coal, and to cause it to cleave parallel to the wall face on the side next the gob, which is unsupported; and the one which acts in a

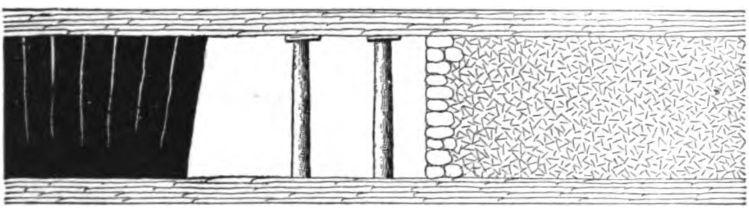


FIG. 549.

horizontal direction, being applied only at the upper surface of the seam, tends to divide the seam parallel to the face, in exceedingly thin scales. Suppose that the seam divides vertically, and in a direction parallel to the face, into slabs of a definite thickness. The horizontal force applied to the upper edge of each of these slabs tends to rotate it upon its lower edge as a center, by which motion the upper edge will be advanced towards the unsupported side, and the wall face will be inclined as shown in Fig. 549. But, as the force acts more intensely as the wall face is approached, the slabs from the face inwards will be less and less inclined, i. e., they will have been separated by a less distance towards the upper edges. Coal is never perfectly homogeneous, and the cleaving force is never applied with the same intensity at every point. Therefore, the seam has a tendency to break up, under the action of the descending roof, into slabs of which will greatly facilitate the getting of the coal by breaking it up into large blocks or slabs, thereby saving much labor in bringing it down. The mass can be subsequently broken up into blocks capable of being handled.

1723. When the face is undercut, as shown in Fig. 550, the pressure of the roof plus the weight of unsupported coal tends to produce a fracture along the line *a b*, and if *a b* be a plane of cleavage, the conditions will be most favorable to the action of the pressure. The foregoing shows that advancing the faces across the principal cleats reduces labor to a minimum, thereby satisfying the conditions of least cost.

But the physical condition of the coal is a consideration of equal importance; for, if the cheaper labor is secured at the cost of an increased amount of slack, the result may really be a loss instead of a gain, when the production is put upon the market.

1724. If the coal be of a weak and tender character, there will be numerous short lines traversing the mass vertically and horizontally, and dividing it into thin slabs and small prisms, instead of the long slabs and few lines of fracture as in the former case. When the "web," or mass, falls, these slabs and prisms are very easily broken across, and the same liability to easy fracture exists during the operation of breaking up the web, or mass, and loading it into cars. A considerable part of the coal is ground small by the roof pressure, especially along the top of the face, where the greatest pressure exists. The final result is a very large amount of slack for longwall mining.

The ease with which the coal falls is a source of danger, which must be provided against by employing sprags to support the "web" while the coal is being undercut. It is evident, under these conditions, that the advantages gained by working "face on" are nullified by the increased percentage of slack.

1725. If the faces are advancing on the end of the coal, or "end on," the pressure of the roof tends to cleave the coal perpendicularly to the cleat or principal cleavage plane, where an incline could be used, because a slant is longer than an incline to reach the same coal, and in pitching seams the *buildings*, or packs, are harder to keep in repair.

The directions of dip and cleat have no fixed relation to each other; sometimes they are parallel, in other seams they are at right angles to each other, and in different districts they may vary from each other through all the points of the compass.

1729. There are many difficulties in the application of longwall to seams exceeding a dip of 12°, but the chief ones are found to be:

1. The tendency of the roof to slip and sink back away from the face, thus taking the desired pressure from the coal. In longwall working one of the great objects aimed at is so to control and regulate the pressure of the roof strata as to keep a *continuous* or *traveling* weight upon the

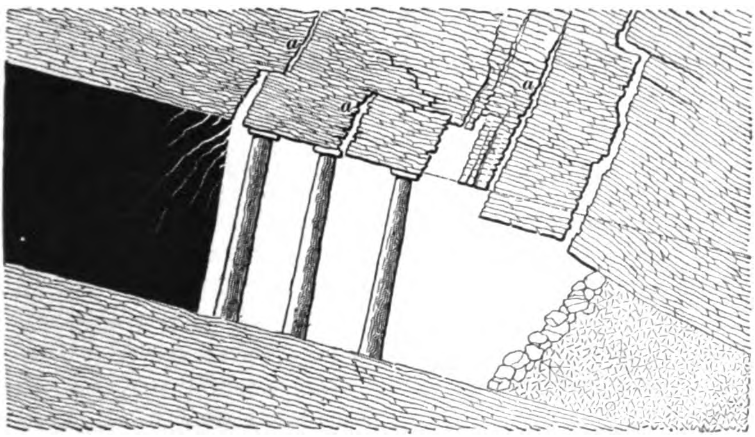


FIG. 551.

coal, thus reducing the labor of mining, and breaking down the coal without the necessity of much, if any, blasting, care being taken not to crush the coal. In flatter seams this is a comparatively easy matter, as with moderate care it is not difficult to control the pressure of the roof with packs and timbering. But, as the inclination increases, there the descending order, the face of the upper seam being kept not less than 30 feet in advance of the face of the lower seam. Still again, in the case of three seams parted by 72 and 75 feet respectively, it is considered best to work the seams in ascending order, and, if possible, in conveniently small districts, so that the lower seam may be completely extracted before work is begun upon the upper seam. When this can not be arranged and the seams have to be worked simultaneously, it is best to keep the face of the lower seam 120 to 150 feet in advance.

1738. The order in which contiguous seams are worked may affect both the roof and the texture of the coal. In gaseous seams the pressure exerted on the face of the coal greatly assists its extraction. The escape of the gas from the coal through the breaks or cracks in the intervening strata, which are caused by the removal of contiguous seams, either above or below it, and the disturbance thereby produced in the equilibrium of pressure in the strata, make the coal tougher and harder to extract. The disturbing elements between two contiguous seams are nearly at right angles to the inclination.

1739. The order of working contiguous seams depends not only on the ease of extraction, but on the market value of the coal as well. If the roof be injured, the result is greater insecurity, which will cause accidents if not provided against. This increased insecurity, in many cases, can be met by increased care in timbering, so that the consideration of the effect on the roof is in most cases subordinate to the effect on the coal. Where the effect is to harden the coal, the price paid the miner per ton is greater, and in the case of a soft coal the percentage of lump coal is increased.

If the increased selling price is greater than the increased cost of producing the coal, which is the case with many soft coals, the hardening is profitable. Coals which are already hard are made less profitable by a further hardening.

4. There will be less risk of accident from falls of roof, because all work would go on beneath a solid top.

5. The coal field will be actually proved before 10 per cent. of the coal is taken out.

6. The (sometimes) disastrous effects of weight upon the gob-road packs and the working faces, due to having to leave solid pillars of coal under important surface buildings, etc., are better provided for, and are hardly felt when working on the *retreating* plan, because the crush or squeeze on the ribs and the top weight thrown upon the gob do not in any way affect the roads in the solid.

7. Main haulways liable to be blocked by extensive falls of top in gob-roads have, in the withdrawing system, every chance of being free from such dangerous and troublesome obstructions.

8. Greater ability to shut off fire, or to allow a portion of the working face to remain idle for a while without much liability to cave or cause trouble. In gob-road mining, the roof is usually so broken up back of the faces that to make a place air-tight is a matter of great difficulty.

1743. In some cases it is necessary to consider not only the strata directly on the top of the coal, but the strata higher up. Many times there is a frail bench on top of the coal, while the strata above it may be exceedingly strong sandstone or limestone, which, notwithstanding the seemingly nice settlement of the top, may be hanging over a large area and exerting a pressure both on the coal face and road packs, in such a way that it may be hard to contend with.

LONGWALL ADVANCING.

1744. In the examples of longwall working, the ventilation is shown by arrows in all plans except those which merely show a very limited portion of a mine. In the latter case it can not be definitely shown, because it is impossible to adopt an arbitrary direction for inflowing and return currents. The question of ventilation in longwall work is a comparatively simple one, and many variations, depending upon local conditions, may be made.

1745. Fig. 554 shows the plan of longwall operation where the top is brittle, the pitch is from 10° to 60°,

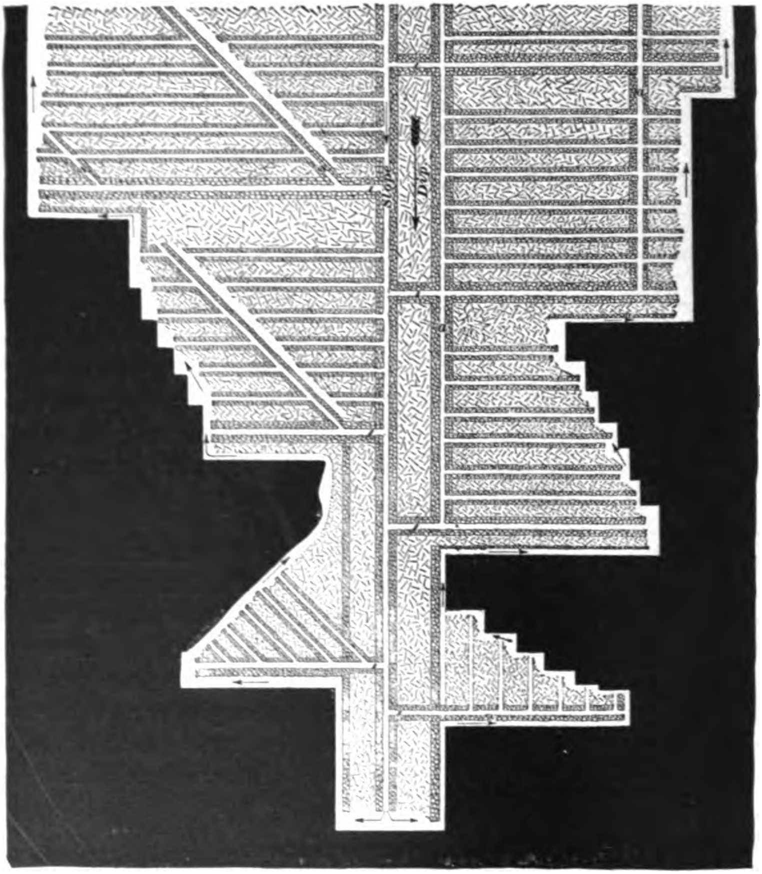


FIG. 554.

the coal does not exceed 3 feet in thickness, and there is sufficient waste from the seam and from opening up the roadways to build the packs, and, to a reasonable extent, to fill the gob.

The upper division on the left of the figure shows a plan of operation when the pitch is such that a slope road *s* can be driven on a pitch of about 6°, over which the coal is lowered to the level below, which in its turn connects with the slope or heading leading to the shaft. The line of face is parallel with the dip, regardless of the line of cleat.

The second division shows the same plan, with the exception that the faces are advanced in steps, principally for the reason already given in Art. **1716.**

The third division on the left shows a plan of working employed where the pitch is such that the cars may be taken to the face, where it is desirable to work the coal "half on," when the cleavage planes are parallel with the dip, or where there is no marked cleavage.

The upper division on the right-hand side shows the plan sometimes employed where the inclination is from 15° to 35°. The faces, irrespective of the line of cleavage, are driven at right angles to the dip and parallel with the level, the coal being lowered to the level by self-acting balance inclines *a*. A chute is sometimes used instead of the balance incline.

The middle division on the right-hand side shows the same arrangement, except that the faces are advanced in steps, for reasons already given.

The third division on the right-hand side shows a manner of mining steep seams. The dip may be such that the coal is delivered by chutes or self-acting balance inclines operating in each road, or by a self-acting (not balance) incline in two roads, the loaded car going down the one road taking the empty car up the other. In the latter case there is no step between the two roads, the step being between each pair of roads.

1746. Fig. 555 shows two methods of circular longwall, one showing the walls, or faces, in steps (shown by dotted lines), and the other showing the wall in a continuous face. The downcast shaft *d*, the upcast shaft *u*, and the stables *h*, *h* are all formed in the shaft pillar, which is rectangular in shape. This plan, with but few modifications, is practised in parts of the central and western coal fields of the United States, as well as in other countries. It is a good method

The roof will settle in roadways from $\frac{1}{3}$ to $\frac{1}{2}$, or more, of the thickness of the seam, depending on the proportion of the gobbing. The work in this figure is laid out with a view of having the same number of working faces in each direction, so that the haulage roads will be equally divided, thereby facilitating the delivery of the output to the shaft bottom. Canvas doors are used until the top has settled, when overcasts and doors of the regular pattern are used. This system is well adapted to shallow depths, where numerous shafts can be sunk cheaper than long roads can be fitted up and maintained for mechanical haulage.

1747. Fig. 556 shows the Missouri plan of longwall operations in seams with a strong and flexible roof, where the seam is from 20 to 22 inches thick. From the bottom of the shaft four entries are driven in the seam, at right angles to each other, for a distance of from 20 to 50 feet. This distance depends on the character and strength of the roof, the depth of the coal beneath the surface, the nature of the underlying clay, and also upon the anticipated period of operation of the shaft. From the ends of these roads cross-cuts are then driven, connecting them with each other. From the exterior sides of these cross-cuts the coal is now mined radially from the shaft, the main entries advancing with the face and being kept open by packwalls and gobbing. This process continues until the face has advanced about 800 feet, and until the distance between the ends of each two adjacent entries is about 1,200 feet. When this stage is reached, the face is still pushed forwards in the same direction as before, but, instead of one entry being left open and packwalls built, two are now left, which radiate from the main entry, one on the right and one on the left, each at an angle of 45° with the original direction of the main entry. In the angle between these two new entries a triangular packwall is built, as a permanent pillar, and beyond it the mining of the coal continues as before. When this has proceeded to such a distance that the haul along the face of the coal to the entries again becomes excessive, bifurcation (dividing into two prongs or forks) of the entries is again resorted to.

The process continues until the limits of the property are reached, unless the coal is at such a shallow depth that it is more economical to sink new shafts than to have a long underground haul.

Part of the shaft *s* is used as the downcast airway, and as

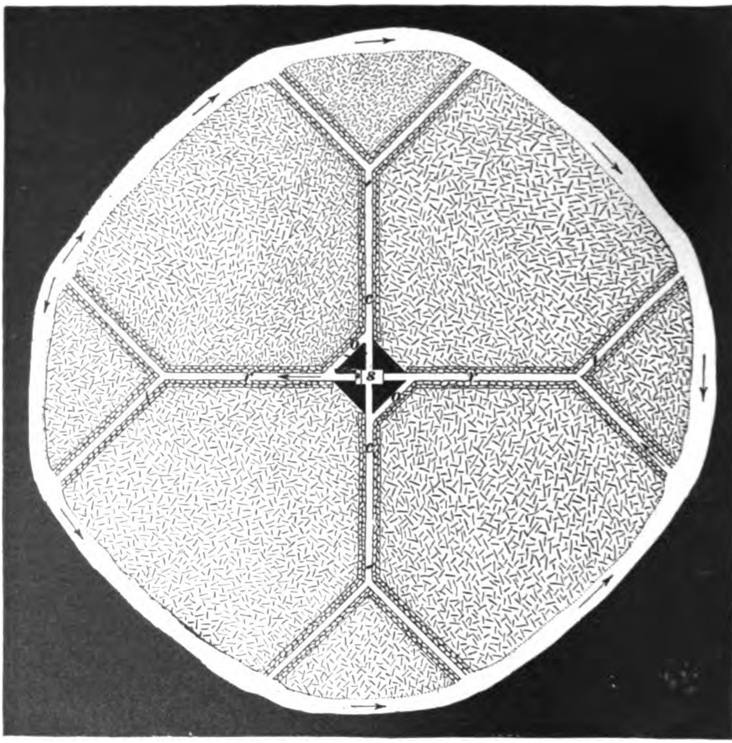


FIG. 556.

the caging is usually done on two opposite sides it is necessary to leave passages *o* on two sides of the shaft pillar in order that the cars may be taken from the roads *r* to the roads *c*, where they will be in the proper position for caging.

Of course it is understood that the track is laid along the miner on each side of the entries, and between these continuous pillars, less carefully packed walls *b* are carried along at right angles to the face as the work advances. These pillars are built of the heavier and larger blocks of waste material, and in between them the smaller and loose material is shoveled. The distance between the pillars is about 6 feet, and the smaller pillars are themselves about 2 feet wide and are tightly wedged to the roof.

1748. Fig. 559 shows a method of longwall pretty much the same as shown in Fig. 555, and much in practice in the

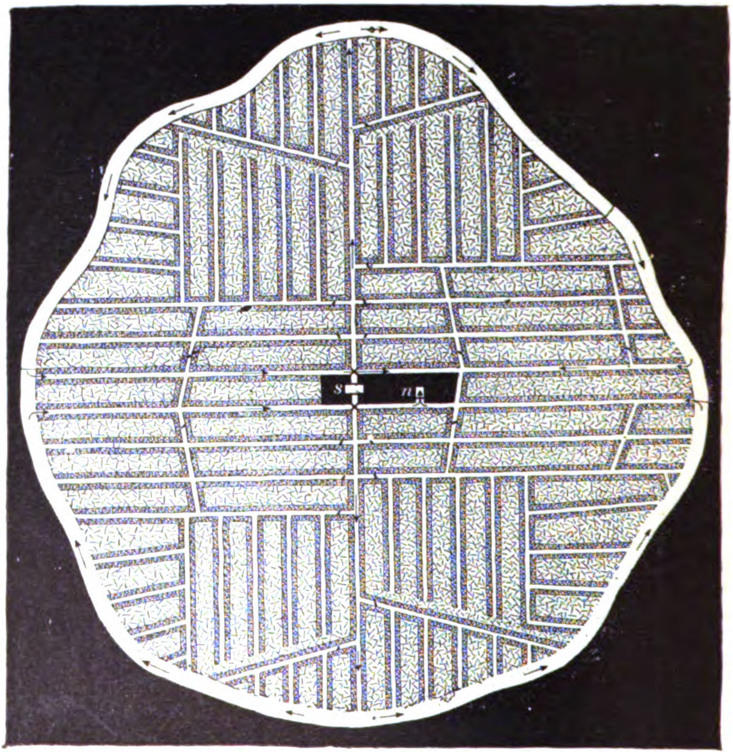


FIG. 559.

central and western coal fields of the United States. It is considered a good plan for low flat seams having a weak and brittle top. In this plan so much space can not be maintained between the face of the coal and the packs as in Fig. 556. The coal is removed directly through numerous roads which connect with one of the principal entries. From the foot of the shaft *s* entries are driven in opposite directions. As soon as sufficient length of face is exposed for mining operations to proceed, the coal is attacked on both sides of the entry along the whole length. As the face advances, the waste material or gob is thrown behind, and at the same time roads are made with packwalls on both sides, at intervals of about 40 feet and at right angles to the main entry. Between two passages or roads, along the main entry, walls of packing are carefully built. The interval between two such roads is known as a "room," and is generally operated by one miner. A careful inspection of the figure will make the system clear to the student. At Leavenworth, Kansas, the dimensions of the main roads are 5 feet wide at the base, 4 feet wide at the top, and 6 feet high, the coal being 22 inches thick.

In this case, packwalls are carried along the entry sides, and on each side of the room road props are placed.

It is the practice, sometimes, to leave a small pillar of coal around the hoisting shaft *s* and sink the air shaft *u* in the gob. When this is done the air shaft is supported at the bottom by carefully built packwalls and stowage. Frequently, after the mine has been fairly developed, it will be found that more efficient ventilation can be obtained by sinking a shallow shaft some distance away from the hoisting shaft, in which case the new shaft will almost invariably be sunk in the gob. Otherwise, it is generally conceded best to leave a pillar of coal to support the shaft, because there is less liability of destroying its alinement through neglect or carelessness of any kind.

1749. Fig. 560 shows a plan of longwall work suitable for seams at great depths, ranging from 2 to 9 feet thick, of almost any texture, and with slight modifications for almost all kinds of top, although best results are obtained when the top is not very weak, and the dip ranges from 14° to 20°.

After the preliminary headings necessary for shaft pillars, ventilation, and drainage have been made, sufficient coal is worked out to allow first packwalls to be built, and from this point the face line is maintained nearly at right angles with the full dip. Two lines of track are laid to facilitate the loading, and in the case of the thinner seams, a slant to

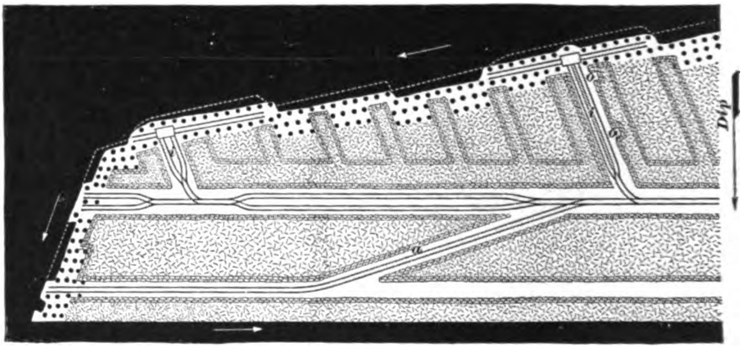


FIG. 560.

be worked by a mule is packed in as shown at *a*. In the case of the thicker seams the road *a* is not driven, and a hand winch is used to raise the coal from the dip side of the level to the level road at the face.

Special attention must be paid to the building of the first packwalls, as it is found that when the roof cuts off at the edge of the solid coal in the level, there is usually more subsidence than in the ordinary working.

1750. The first packwalls in the thinner seams may be built with débris brought from other parts of the mine or with material taken from the top or bottom of the roads in the solid. As soon as a sufficient length has been built, taking down top in the level is commenced. About 5 feet of roof is taken down in a seam 4 feet thick, care being taken not to take it down in advance of the packs, in order that the top rock will not be shattered over the position of the packwalls. Excepting where the workings are disturbed by subsequent operations, in overlying or underlying seams, very little further work is required in the main road unless in the level. This mass then has a tendency to slip down hill. It will also be noticed, by referring to the figure, that slipping will more readily take place if a sufficient breadth of coal were not worked out on the high side of the packwall, and if the first break should take place in the line *g h*.

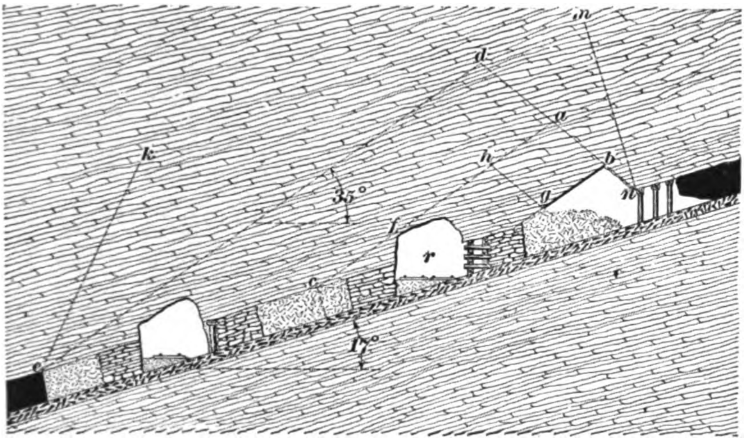


FIG. 561.

When sufficient breadth of coal is taken out on both sides of the roadway to cause the break to take the lines *b d*, *d e*, there is sufficient lateral support left in the loosened mass of roof *b d e* to prevent the downhill slipping, and at the same time the greater weight of that portion directly overlying the high side packing tends to exert a directly vertical pressure. The lines *e d* and *d b* show the direction of the first breaks, while the lines *e k* and *n m* show the direction of the main breaks.

1755. Fig. 562 shows a method of longwall which is largely practised in low seams, in which the regular mine car can not be taken along the coal face. The roadways *r* are turned off the heading or haulway *h* at intervals of about 30 yards, and when they are driven up 10 yards, lifts of 8 or 10 yards are turned off to the right and left and driven parallel to the heading for 15 yards, or one-half the distance between the roadways. Two men at a time work in each

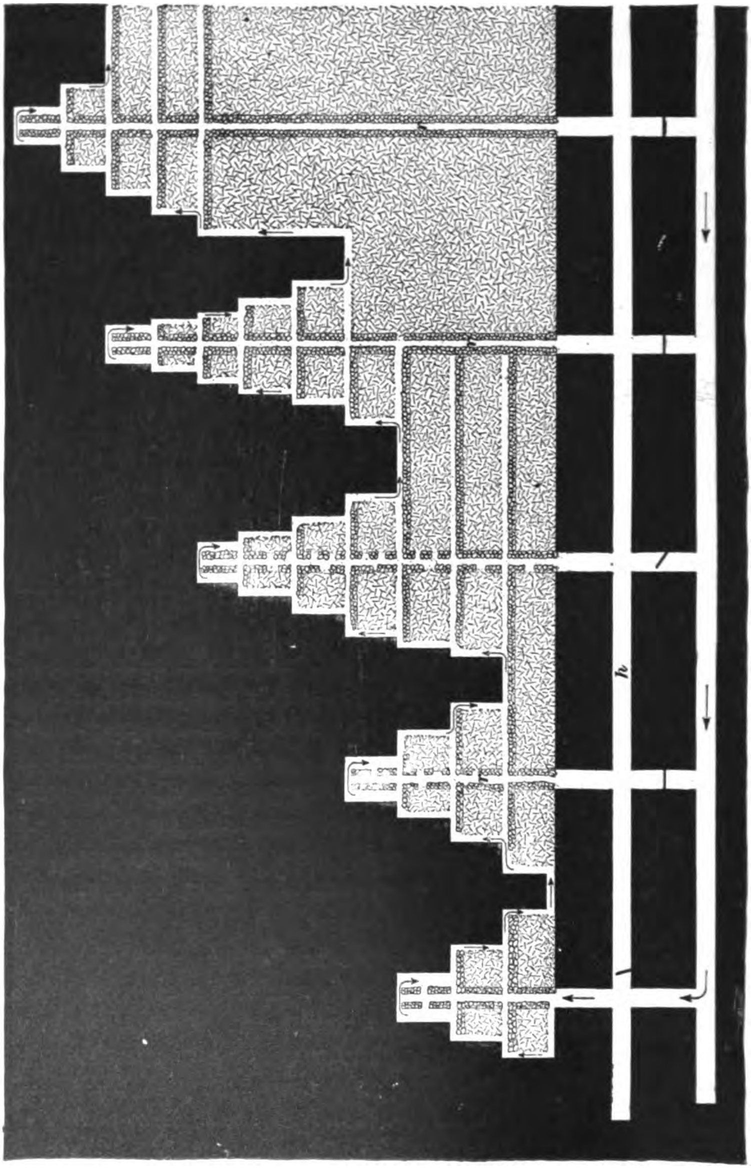


FIG. 301.

lift. Sometimes the roadways are turned off at intervals of only 10 or 12 yards, in which case the coal is filled directly into the cars without the use of buggies to convey the coal to the road side, as is done when the distance between roadways is 30 or 40 yards. Packwalls 6 feet wide are built along each side of the roadways and on but one side in the lifts, as shown in the figure.

When the roadways are close together this system entails a great amount of extra cost in building packwalls and taking down roof, which brings the price paid per ton up to that paid when the pillar and chamber method is used; but, since more lump coal can be produced by the longwall method, the advantage is in its favor, and it is therefore adopted. The cleavage planes are parallel to the dip.

One objection is that under a fairly strong top the packwalls are so close together that sometimes the top does not fall, and when there is not enough refuse to thoroughly stow the open space, or gob, these packwalls become a source of trouble and danger, especially in gassy seams.

1756. Fig. 563 shows a method of longwall as practised at Pemberton Colliery, in Lancashire, England. The seam dips at an inclination of 4° to 5°. Two seams are worked; the one from which the example is taken is 1,698 feet from the surface, and the other is 180 feet below it. The coal from the upper seam is lowered to the lower seam through a pit called a **blind pit,** with two cages, the rope going over a clip pulley. One car is lowered at a time, the full one pulling the empty one up. The coal is brought from the level next the face to the top of the blind pit by means of a self-acting incline.

The roads *r* are driven to the full rise and are 30 yards apart from center to center. They are cut off every 300 feet by levels *e* running about at right angles to them. These levels are 8 feet wide and have packs 12 feet wide built on each side. The roads to the faces or "brows" are 7 feet wide and there are 9-foot packwalls on each side (see Fig. 565). Two feet of top is taken down in the roadway for packing.

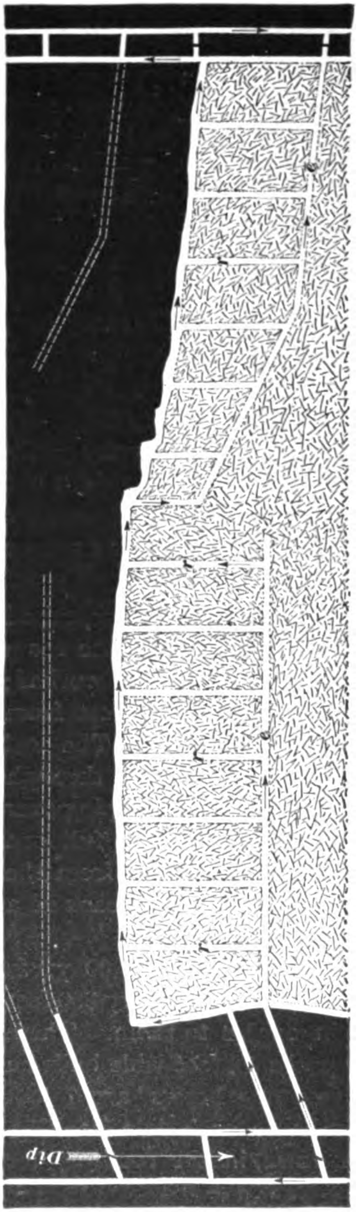


FIG. 563.

There is no regular holing or mining, but when the coal is mined it is done in the 10-inch coal in the center (see Fig. 564). The bottom coal is then lifted up and the top coal supported on props. When these are knocked out the top coal falls. A slight heaving of the bottom greatly assists in taking up the bottom coal. Props and sprags are put in by the miner when required. Four men are in the place on each side of the road, and they deliver their own coal to the self-acting incline.

1757. In addition to the 9-foot packwalls carried on each side of the roads to the face, a double row of chocks *c*, *c* (Figs. 564 and 565), 6 feet apart, is carried all the way along the face. The two rows are laid 5 feet apart, and the car track along the face is laid between them (see Fig. 565). As a third row of chocks is put in, the last one is drawn and shifted forwards. The roof then breaks off behind the chocks. Each chock consists of billets main road or self-acting incline plane *i*, down which all the coal is sent to the level *c*. Three feet of the shale roof is taken down in the roads. Below the 2 feet of fireclay in which the holing is done, directly beneath the coal, there is a dark sandstone. The seam is 5 feet 2 inches thick and composed of several layers varying from each other in thickness and quality.

1759. The packs are within 4 feet of the face when the holing or mining is begun, and there is a row of 8-inch props $4\frac{1}{2}$ feet apart along the face. The miners begin at the center and go on holing to both sides, putting in sprags *b* (Fig. 567), 2 feet long, every 6 feet. When necessary, short sprags *a* (Fig. 567), about 15 inches long, are put in

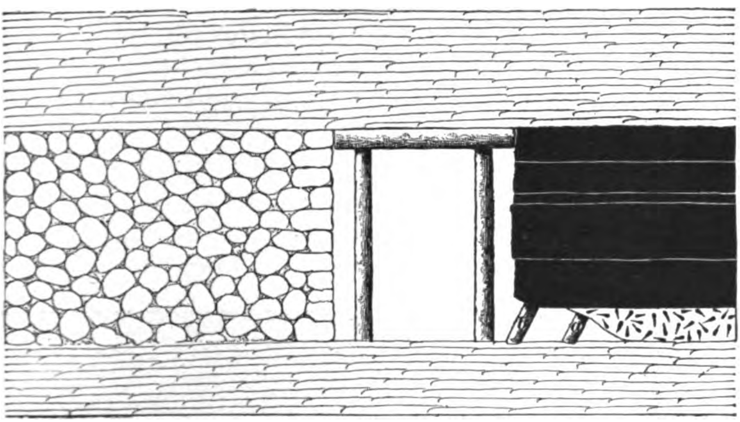


FIG. 567.

underneath the coal, but there is no fixed distance that they should be apart. While the coal is standing on sprags a **shearing** or vertical holing is made at the road-head, 2 feet wide at the beginning and tapering to 3 inches at a depth of about 5 feet. After this is done the miners begin by taking out three or four sprags, and allow the coal they supported to fall.

This is loaded and the roadway laid along the face as shown at *r*, in Fig. 568, which is a plan showing two adjacent rooms with packwalls and posts. Props and sets of timber are set up over the road (see Fig. 567) about every 4½ feet. One end of the cross-bar is sometimes let into the coal some 3 or 4 inches, and the other end is supported on a prop. When this is done other sprags further on are taken out and the

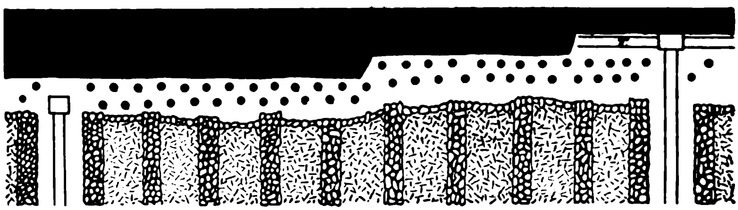


FIG. 568.

coal is loaded. The process is repeated until the end of the room is reached on both sides. When there are two rows of props which are about 5 feet apart behind the sets of timber over the road, the packwalls are built forwards and the props removed. Where the roof is weak or tender, packs about 6 feet wide and 9 feet apart are built of the débris from the road.

1760. Fig. 569 is reduced from the working plan of the Florence Colliery, Longton, in the North Staffordshire

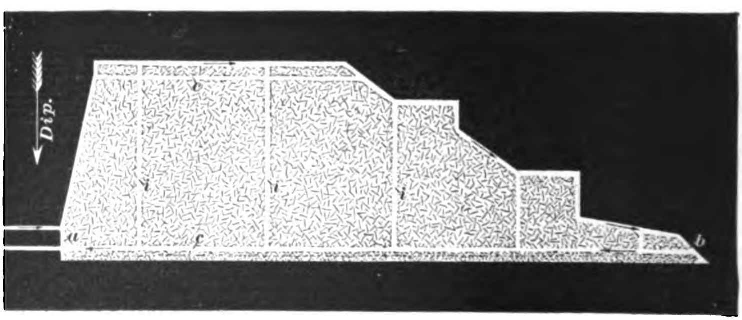


FIG. 569.

(England) district. The depth to the coal is 2,238 feet and it has an inclination of about 8°. Two levels, 10 yards apart, are driven from the shaft bottom for a distance of 1,050 feet, to down by blasting. The props are from 5½ to 6 inches in diameter at the thin end, and there are two rows 4½ feet apart with the props in each row 6 feet apart. If the roof is tender, chocks made of broken timber and built on small coal are put in. There are canvas sheets *s* (Fig. 570) put in from the face for some distance back into the wastes, or gobs, between the packs, and the air is made to travel into the gob.

1762. Fig. 572 shows a system practised in Northern France and Belgium in seams pitching from 10° to 60°, but it is most suitable for pitches ranging from 30° to 60°. The more moderately inclined seams are worked by a road carried up from one level to another, and branch roads are turned off right and left from it about every 20 yards, measured along the inclination of the seam. The coal is taken out for a distance of from 150 to 300 feet on each side of the main incline *i*, and the face presents a series of steps. At intervals slope roads *s* are formed through the gob, cutting off

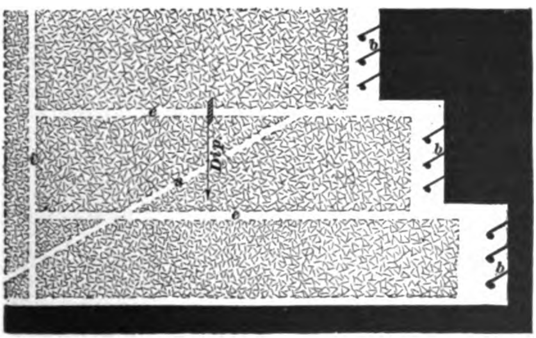


FIG. 572.

the upper levels. When the inclination is 30° to 60°, the track is only laid along the main levels *e*, *e*, which connect with a main self-acting incline *i*. The coal, when loosened by the miner, gravitates down to these levels along the face, and is there loaded into cars. Each face is 60 feet long (measured on the dip), and is worked by four men. For convenience and safety, these men place pieces of board *b*

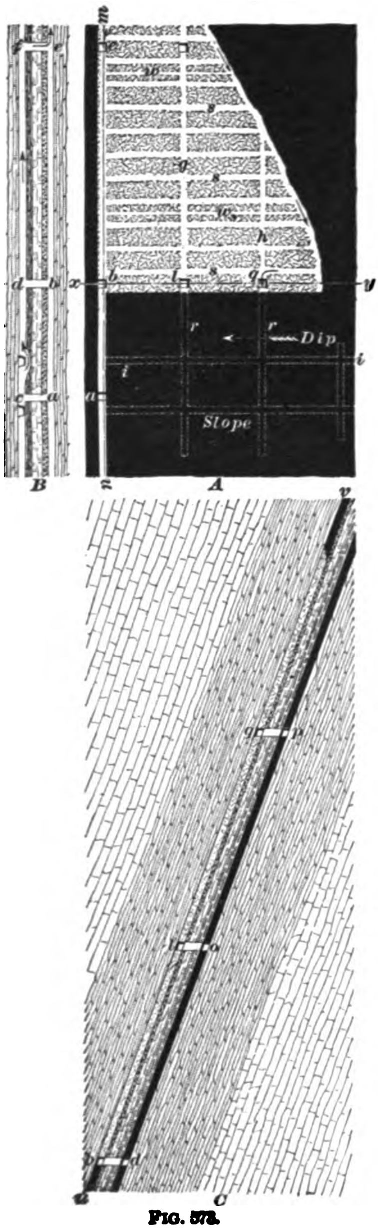


FIG. 573.

packwalls. For the convenience of the miners the walls are arranged so that each has a long rise and a short dip side. The coal is dropped down the chute, at the bottom of which it is loaded into cars.

At intervals of about 210 feet traveling roads *w* (*A*) are formed for the purpose of affording convenient access to the working face at different points. These are built similar to the chutes and are furnished with ladders.

While the longwall working is progressing, roads *r*, *r* (*A*) are driven in the lower seam, at intervals of about 120 feet, and cross-cuts *o l*, *p q* (*C*) are driven therefrom to the great seam, so as to strike this seam before the longwall heading reaches their level. From these cross-cuts intermediate levels *g*, *h* (*A*) are carried across the working faces as they come up, cutting off the chutes. The roads for these immediate levels are laid upon the stowage, and the rise side of the roadway is pillared with wood as in the level below.

The level *d f* (*B*) in the

sufficient to hold them in position. Many hundreds of these pillars have been put in, and they have never been known to slip.

As soon as the chutes *s* (Fig. 573) in a section of a level, as *b c*, in the lower level, are cut off by the level *g* above, the pillaring is taken out in the corresponding section *b c*, and the wood so drawn is used a second time, and, when used in connection with a little new wood, even a third time.

1766. The distance between levels is determined chiefly by the inclination of the seam and the condition of the pack-walls of the chutes. As the inclination increases, the coal falls down the chute with greater velocity, and the breakage, consequently, become more serious. The iron-stone with which the chutes are built varies considerably in strength, in some places forming very indifferent building material, and when the packwalls begin to give way, the expense of repair is very great. It, therefore, becomes simply a question of arithmetic at what point the reduced value of the output, together with the cost of maintenance of chutes, will warrant the outlay for a new cross-cut and intermediate level.

The shield, or battery, *b c* (Fig. 574) stops the coal at the mouth of the chute, protects the men while passing, and makes a convenient platform off which the coal is loaded into the car. It will be noticed that the battery closes the chute on the outer side. Experience has shown that, when it is so arranged, the air current is much more easily led into the face of the level, and is less dependent upon the screen-doors, which, it is needless to point out, are exceedingly difficult to maintain in perfect condition. The coal is generally worked in lifts of from 360 to 480 feet, and is divided into panels of about 1,200 feet in length.

1767. The plan shown in Fig. 575 is used very successfully on pitches ranging from 70° to 90°. The brake incline and haulage roads are made in the lower seam, as in Fig. 573. Narrow levels *b* in the solid are branched off this incline at intervals of 56 feet between centers, and from each level a cross-cut *c* is driven to the great seam. The longwall working is commenced on the bottom level, 6 feet of stowage is kept below the rails, and the rise side of the road is pillared continuously, as already described in Art. **1763.** The clear height of the road is 5½ feet. The rise side of the working face is kept trailing, so as to form an angle of 45° with the road. As soon as this level has been opened up

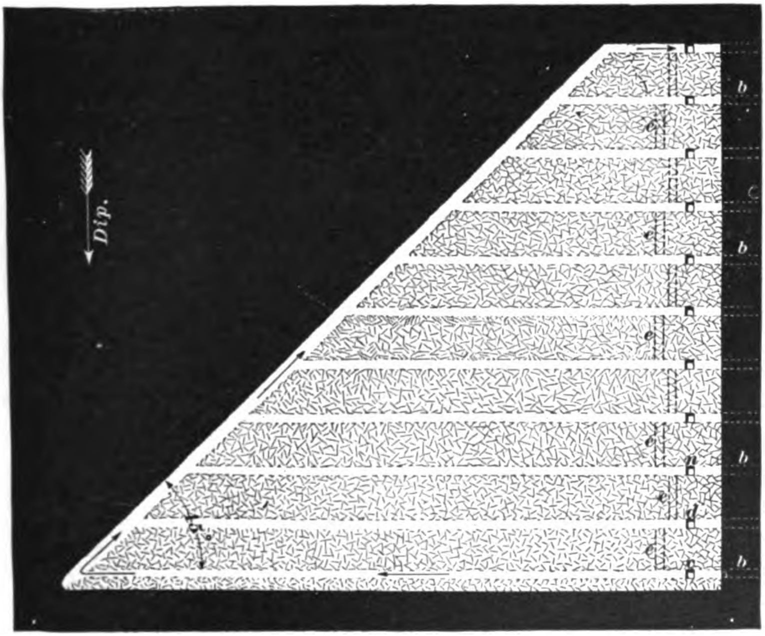


FIG. 575.

sufficiently to let the rise side reach the level of the cross-cut *d*, a road from this cross-cut is laid on the top of the stowage, its rise side being pillared in the same manner as that of the lower level, and the working is extended upwards to the cross-cut *n*, and so on to the top of the brake incline.

The bottom coal generally stands well enough in the roads without timber. The roof, which here forms one side taken down, and the débris then acts as a flat at the top of the inclined roads in the upper seam. The position of these seams, and the mode of working them, which is shown in Fig. 576, makes a most convenient flat at a small cost. The cars from the second seam join those from the larger seam at the top of the self-acting incline plane *i*.

1769. Where the seams are highly inclined, very much contorted, and broken up, it is the practice in some districts to sink a vertical shaft *s* (Fig. 577) and drive cross-cuts *c* at

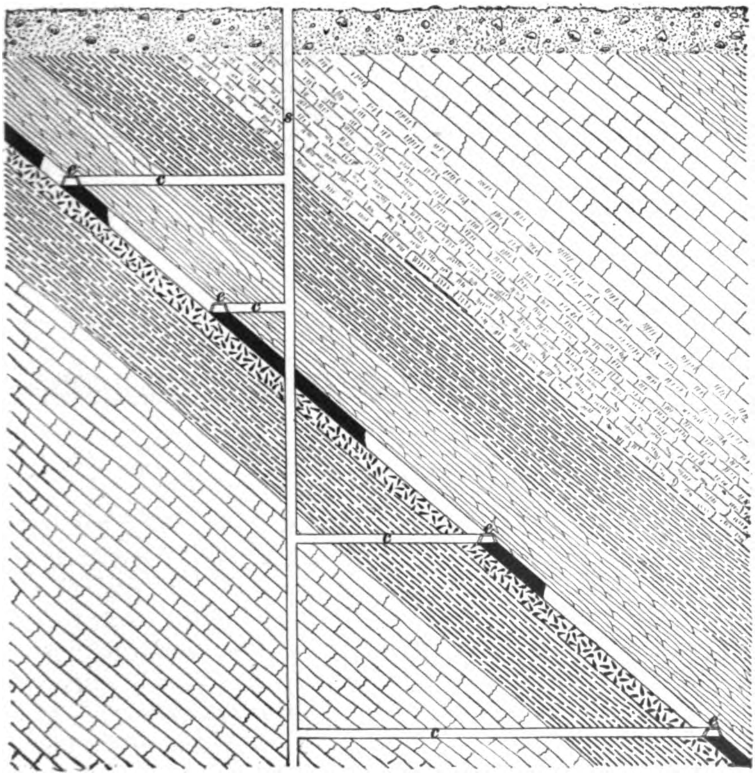


FIG. 577.

regular distances apart. At the points of intersection of these cross-cuts with the seam, levels *e* are driven right and left. These levels follow the strike of the seam, and as the inclination is very irregular they are very crooked. The coal is then worked to the rise side of these levels, as shown in the figure.

1770. Fig. 578 shows a method of mining a moderately inclined seam 21 feet thick, in the district of Grande Combe, in the south of France. The plan *A* is taken by supposing the strata to be removed above the line *s t u v w x y z* shown on section *B* which is taken along the line *a b* of the plan *A*, and drawn by increasing the vertical dimensions.

The primary work is in the lower 7 feet of the seam in

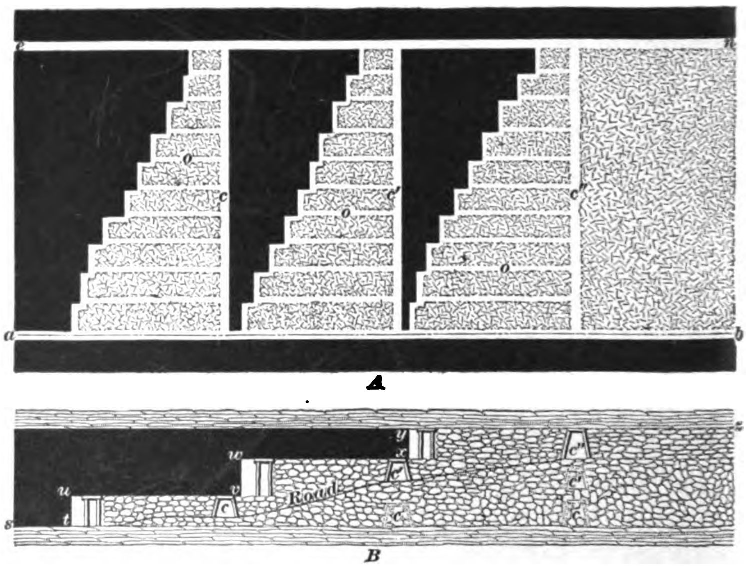


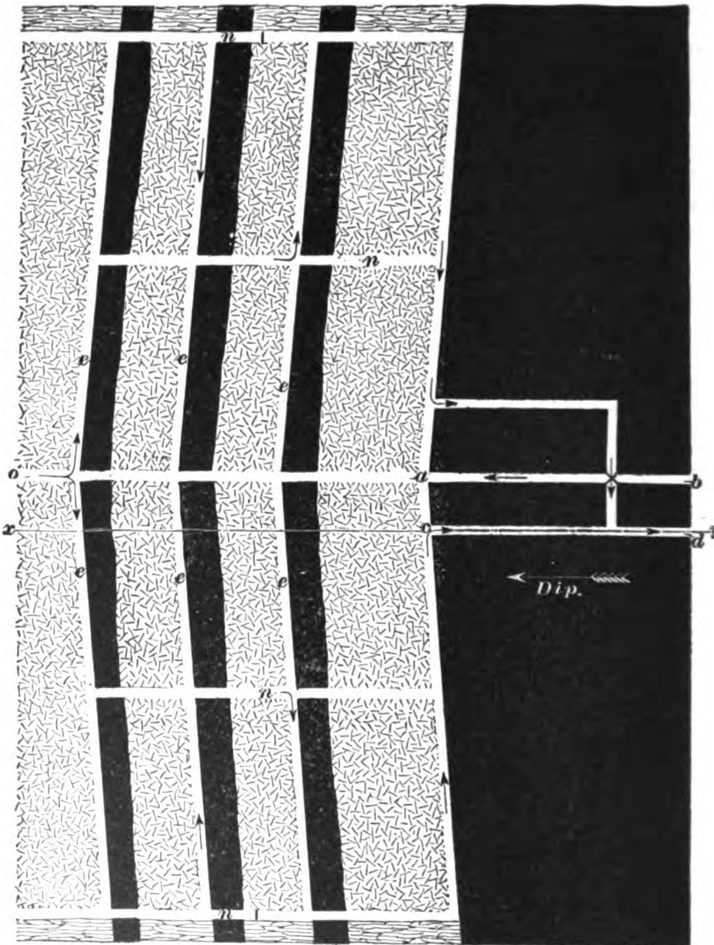
FIG. 578.

which a level *a b* is driven, and from this level inclines *c* from 240 to 300 feet apart are driven to the full rise. Every 30 feet roads *o* are turned off these inclines parallel with the main level. The packs are made of material sent down from the surface into the workings. The car loaded with stone gravitates along the road *c n* to the working places, where it is unloaded and again filled with coal and returned along the heading *a b*.

When the packs consolidate, the floor is heaved up and the

The driver in charge of the trip would first proceed to the cross-cut *k*, to which point there should be a double track from the foot of the shaft, and then if no driver was coming out of the headings *g* to the right, he would pass through the cross-cut *k* and continue along the straight heading, noticing when he came near the diagonal cross-cut *l* that no driver was coming out of the heading *c* to the right, in which case he would still continue along the straight heading and pass through the cross-cut *m*, where he would again observe that no driver was coming out of the headings *c* to the left, before he would pass through the cross-cut *q*, along the straight heading *c*, through the cross-cut *p*, and finally along the heading *d* to the point *x*. After placing his empty trip, the driver would lead his horse or mule to the point *y*, where he would hitch on the loaded trip and pass out the same heading *d* as he came in until he reached the point *n*, where he would turn and pass along the straight heading directly to the point *r*, where he would again turn and go straight to the landing with his loaded trip. It should be observed that the driver with the empty trip must be on the lookout for drivers coming out with loaded trips, and that the driver coming out has no charge upon him or stops to make.

When, from circumstances before mentioned, it is necessary to drive the pairs of headings *d* close together, only one heading of each pair need have a track in it, because one or more headings are usually assigned to a driver, and there is no danger of one driver running into the other. Under such conditions the arrangement of the cross-cuts, as shown in the headings *c*, is efficient; if, however, the conditions of the mine are such that the pairs of headings *d* can be driven a considerable distance apart, say 100 or 200 yards, then each heading of the different pairs will be provided with a track on which the loads and empties pass over. With this situation of affairs, the cross-cut *p* should connect with the first heading of the extreme left-hand pair *d* rather than with the second of that pair, as shown in the figure, in order to facilitate the haulage from both headings. Similar arrangements should be made at all junctions of the pairs



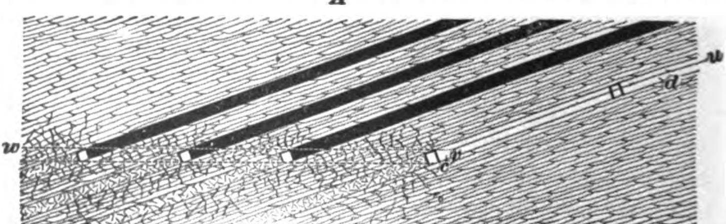


FIG. 561.

the number of permanent haulways to be maintained. It

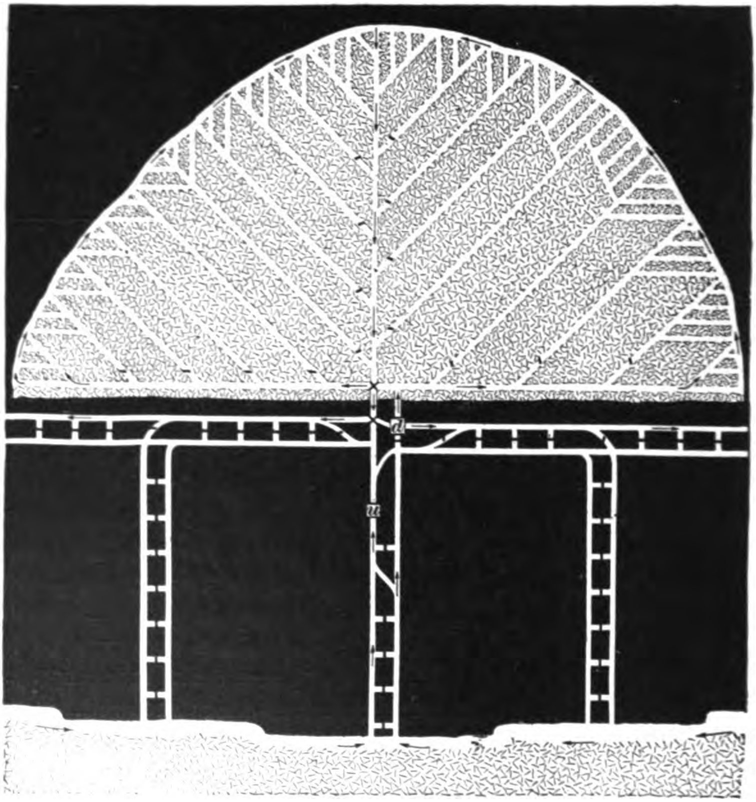


FIG. 582.

is understood that packwalls and chocks are built along the roads, as described through this subject.

1781. This plan of working is suitable for seams up to 3 feet thick, having a weak top, a pitch not greater than 20°, and situated at almost any depth. It is largely the method from which most of the longwall practised in the western United States has been copied.

1782. The lower portion, where the coal is from 4 to 4½ feet thick, is worked on the retreating plan. Narrow head-proper direction will depend the best manner of supporting the roof and of getting the greatest amount of lump coal.

2. Whether the working face should be kept in a continuous line or stepped; for this also affects the maintenance of the roof and the size of the coal obtained.

3. The rate of advance of the working face. Sometimes it is advantageous to allow the web of coal to remain unsupported upon the sprags or cockers until the pressure of the roof acts upon it; while, on the other hand, it is sometimes best to advance the working face as fast as possible.

4. The proper building of the packwalls and the stowage of the gob. The packwalls should be built as strong as possible, carried close up to the roof, and kept well up to the face; where there is sufficient available material it is always best to stow the gob completely.

1785. In conclusion it is scarcely necessary to say that the system is applied to seams varying much in thickness, depth, and in the nature of their roof and floor. With a straight or uniformly curved face and the bearing in properly done, it is undoubtedly the best system to obtain the greatest percentage of lump coal and to get the largest proportion of the entire seam at a minimum cost; but where roadways must be made close together and the roof and floor are hard, requiring the use of explosives, it is doubtful if the system has any advantage over the pillar and chamber method.

The use of longwall methods in the United States is becoming more general; and the fact that it is now being recognized that our supply of coal is limited, *exhaustive mining* is becoming of *great* importance in determining mining methods.

1786. It is claimed that longwall, particularly longwall retreating, could be applied to many of the low and moderately inclined anthracite seams with almost inestimable advantages over the present system; indeed, theory strongly upholds that such would be the case, and a great deal of experience on the Eastern Continent corroborates the theory.

The principal difficulty of introducing longwall in the anthracite region for some seams seem to be that no operator desires to take the risk of giving the system a fair trial in the hands of experienced men, so long as he can profitably operate upon the established plan.

1787. Longwall advancing has been tried on a small scale in some parts of the anthracite region without success. Longwall retreating, which seems to be the most likely method of working many anthracite seams on a more economic and exhaustive plan than is now in use, has not yet been tried. It not only requires a radical change in the mine cars, but also requires that the operator wait until nearly all narrow work is driven before he can get any returns, something very much in opposition to the principles (perhaps conditions) of the American operator.

CREEP IN LONGWALL.

1788. Creep in longwall is simply a swelling up of the bottom in the roads, caused by the weight resting heavily on the roadside packs. Where there is a soft fireclay (hard fireclay may be made soft by moisture) floor, and the gob is not very fully stowed, the packs will receive a great amount of pressure, and the soft fireclay naturally swells up in the spaces on each side of the packs, and as the heaving up meets with practically no resistance in the roadways, they may become closed up entirely. There are few cases of longwall where creep does not take place to some extent, although, where the gob is stowed completely, the weight of the overlying strata is distributed almost entirely over the bottom, and the conditions for creep—the concentration of the superincumbent pressure upon a small area of the bottom—are entirely avoided.

1789. Fig. 583 shows a longitudinal section *A* and a cross-section *B* through a road in longwall workings in which a creep has occurred. The cross-section *B* is taken through the line *a b*, and the longitudinal section through the line *f e*. It will be observed that the packwalls *p* on

MECHANICS.

(PART 1.)

MATTER AND ITS PROPERTIES.

1799. Matter is anything that occupies space. It is the substance of which all bodies are composed. Matter is composed of *molecules* and *atoms.*

1800. A **molecule** is the smallest portion of matter than can exist without changing its nature.

1801. An **atom** is an indivisible portion of matter.

Atoms unite to form molecules, and a collection of molecules form a mass or body.

A drop of water may be divided and subdivided, until each particle is so small that it can only be seen by the most powerful microscope, but each particle will still be water. Now, imagine the division to be carried on still further, until a limit is reached beyond which it is impossible to go without changing the nature of the particle. The particle of water is now so small that, if it be divided again, it will cease to be water, and will be something else; we call this particle a *molecule.*

If a molecule of water be divided, it will yield two atoms of hydrogen gas, and one of oxygen gas. If a molecule of sulphuric acid be divided, it will yield two atoms of hydrogen, one of sulphur, and four of oxygen.

It has been calculated that the diameter of a molecule is larger than $\frac{1}{1250000000}$ of an inch, and smaller than $\frac{1}{500000000}$ of an inch.

1802. Bodies are composed of collections of molecules. Matter exists in three conditions or forms: *solid*, *liquid*, and *gaseous.*

divisibility, *porosity*, *compressibility*, *expansibility*, and *elasticity*.

1808. Extension is the property of occupying space. Since all bodies must occupy space, it follows that extension is a general property.

By **impenetrability** we mean that no two bodies can occupy exactly the same space at the same time.

1809. Weight is the measure of the earth's attraction upon a body. All bodies have weight. In former times it was supposed that gases had no weight, since, if unconfined, they tend to move away from the earth, but, nevertheless, they will finally reach a point beyond which they can not go, being held in suspension by the earth's attraction. Weight is measured by comparison with a standard. The standard is a bar of platinum owned and kept by the Government; it weighs one pound.

1810. Inertia means that a body can not put itself in motion nor bring itself to rest. To do either, it must be acted upon by some force.

1811. Mobility means that a body can be changed in position by some force acting upon it.

1812. Divisibility is that property of matter which indicates that a body may be separated into parts.

1813. Porosity is that property of matter which indicates that there is space between the molecules of a body. Molecules of a body are supposed to be spherical, and, hence, there is space between them, as there would be between peaches in a basket. The molecules of water are larger than those of salt; so that when salt is dissolved in water, its molecules wedge themselves between the molecules of the water, and unless too much salt is added, the water will occupy no more space than it did before. This does not prove that water is penetrable, for the molecules of salt occupy the space that the molecules of water did not.

Water has been forced through iron by pressure, thus proving that iron is porous.

1814. **Compressibility** is that property of matter which indicates that the molecules of a body may be crowded nearer together, so as to occupy a smaller space.

1815. **Expansibility** is that property of matter which indicates that the molecules of a body may be forced apart, so as to occupy a greater space.

1816. **Elasticity** is that property of matter which indicates that if a body be distorted within certain limits, it will resume its original form when the distorting force is removed. Glass, ivory, and steel are very elastic.

1817. **Indestructibility** indicates that matter can never be destroyed. A body may undergo thousands of changes; be resolved into its molecules, and its molecules into atoms, which may unite with other atoms to form other molecules and bodies entirely different from the original body, but the same number of atoms remain. The whole number of atoms in the universe is exactly the same now as it was millions of years ago, and will always be the same. *Matter is indestructible.*

1818. **Special properties** are those which are not possessed by all bodies. Some of the most important are as follows: *Hardness*, *tenacity*, *brittleness*, *malleability*, and *ductility*.

1819. **Hardness** is that property of matter which indicates that some bodies may scratch other bodies. Fluids and gases do not possess hardness. The diamond is the hardest of all substances.

1820. **Tenacity** is that property of matter which indicates that some bodies resist a force tending to pull them apart. Steel is very tenacious.

1821. **Brittleness** is that property of matter which indicates that some bodies are easily broken; as glass, crockery, etc.

Rule.—*Divide the distance by the time.*

Let s = distance traveled by moving body;
v = uniform velocity of body;
t = the time.

Then, $$v = \frac{s}{t}. \qquad \textbf{(90.)}$$

EXAMPLE.—The piston of a steam-engine travels 3,000 feet in 5 minutes; what is its velocity in feet per minute?

SOLUTION.—Here 3,000 feet is the distance, and 5 minutes is the time. Applying formula **90**,

$$v = \frac{s}{t} = \frac{3,000}{5} = 600 \text{ feet per minute. Ans.}$$

CAUTION.—Before applying the above or any of the succeeding rules, care must be taken to reduce the values given to the denominations required in the answer. Thus, had the velocity been required to have been in feet per second instead of feet per minute in the above example, the 5 minutes should first be reduced to seconds before dividing. The operation would then have been 5 min. = 5 × 60 = 300 sec. Then, according to the formula,

$$v = 3,000 \div 300 = 10 \text{ ft. per sec. Ans.}$$

Had the velocity been required in inches per second, it would have been necessary to reduce the 3,000 feet to inches and the 5 minutes to seconds before dividing. Thus, 3,000 ft. × 12 = 36,000 in. 5 min. × 60 = 300 sec. Now, applying the formula,

$$v = \frac{36,000}{300} = 120 \text{ in. per sec. Ans.}$$

EXAMPLE.—A railroad-train travels 50 miles in 1½ hours; what is its average velocity in feet per second?

SOLUTION.—Reducing the miles to feet and the hours to seconds, 50 miles × 5,280 = 264,000 ft. 1½ hours × 60 × 60 = 5,400 sec. Applying formula **90**,

$$v = \frac{264,000}{5,400} = 48\tfrac{8}{9} \text{ ft. per sec. Ans.}$$

1828. To find the distance which a body would travel in a given time with a given velocity:

Rule.—*Multiply the velocity by the time,*

or $$s = v\,t. \qquad \textbf{(91.)}$$

EXAMPLE.—The velocity of sound in still air is 1,092 feet per second: how many miles will it travel in 16 seconds?

SOLUTION.—Reducing the 1,092 ft. to miles, the velocity is

$$\frac{1,092}{5,280} \text{ mile per second.}$$

Applying formula **91**,

$$s = v\,t = \frac{1,092}{5,280} \times 16 = 3.31 \text{ miles, nearly. Ans.}$$

EXAMPLE.—The piston speed of an engine is 11 ft. per sec.; how many miles does the piston travel in 1 hour and 15 minutes?

SOLUTION.— 1 hour and 15 minutes reduced to seconds = 4,500 seconds = the time. 11 feet reduced to miles = $\frac{11}{5,280}$ mile = velocity in miles per second. Applying the formula,

$$s = \frac{11}{5,280} \times 4,500 = 9.375 \text{ miles. Ans.}$$

1829. To find the time it will take a body to move through a given distance with a given uniform velocity:

Rule.—*Divide the distance, or space passed over, by the velocity.*

$$t = \frac{s}{v}. \qquad \textbf{(92.)}$$

EXAMPLE.—Suppose that the radius of the crank of a steam-engine is 15 inches and that the shaft makes 120 revolutions per minute, how long will it take the crank-pin to travel 18,849.6 feet?

SOLUTION.—Since the radius, or distance from the center of the shaft to the center of the crank-pin, is 15 in., the diameter of the circle it moves in is 15 in. × 2 = 30 in. = 2.5 ft. The circumference of this circle is 2.5 × 3.1416 = 7.854 ft. 7.854 × 120 = 942.48 ft., distance that the crank-pin travels in one minute = velocity in feet per minute. Applying the formula,

$$t = \frac{s}{v} = \frac{18,849.6}{942.48} = 20 \text{ min. Ans.}$$

EXAMPLE.—A point on the rim of an engine fly-wheel travels at the rate of 150 feet per second; how long will it take to travel 45,000 feet?

SOLUTION.—Using formula **92**,

$$t = \frac{45,000}{150} = 300 \text{ sec.} = 5 \text{ min. Ans.}$$

EXAMPLES FOR PRACTICE.

1. A locomotive has drivers 80 inches in diameter. If they make 293 revolutions per minute, what is the velocity of the train in (*a*) feet per second? (*b*) miles per hour? Ans. { (*a*) 102.277 ft. per sec. (*b*) 69.734 mi. per hr.

2. Assuming the velocity of steam as it enters the cylinder to be 900 feet per second, how far could it travel, if unobstructed, during the time the fly-wheel of an engine revolved 7 times, if the number of revolutions per minute were 120? Ans. 3,150 ft.

3. The average speed of the piston of an engine is 528 feet per minute; how long will it take the piston to travel 4 miles? Ans. 40 min.

4. A speed of 40 miles per hour equals how many feet per second? Ans. 58⅔ ft.

5. The earth turns around once in 24 hours. If the diameter be taken as 8,000 miles, what is the velocity of a point on the earth in miles per minute? Ans. 17.45⅓ mi. per min.

6. The stroke of an engine is 28 inches. If the engine makes 11,400 strokes per hour, (*a*) what is its speed in feet per minute? (*b*) How far will this piston travel in 11 minutes? Ans. { (*a*) 443⅓ ft. per min. (*b*) 4,876 ft. 8 in.

FORCE.

NEWTON'S LAWS OF MOTION.

1830. A **force** is that which produces, or tends to produce or destroy, motion. Forces are called by various names, according to the effects which they produce upon a body, as *attraction*, *repulsion*, *cohesion*, *adhesion*, *accelerating* force, *retarding* force, *resisting* force, etc., but all are equivalent to a push or pull, according to the direction in which they act upon a body.

1831. That the effect of a force upon a body may be compared with another force, it is necessary that three conditions be fulfilled in regard to both bodies. They are as follows:

1. *The point of application, or point at which the force acts upon the body, must be known.*

2. *The direction of the force, or, what is the same thing, the straight line along which the force tends to move the point of application, must be known.*

3. *The magnitude or value of the force, when compared with a given standard, must be known.*

The unit of magnitude of forces will always be taken as one pound, and all forces will be spoken of as a certain number of pounds.

1832. In practice, force is always regarded as a pressure; that is, a force may always be replaced by an equivalent weight. Thus, a force of 20 lb. acting upon a body is regarded as a pressure of 20 lb. produced by a weight of 20 lb. The tendency of a force is always to produce motion in the direction in which it acts. The resistance may be too great to cause motion, but it *always tends* to produce it.

1833. The fundamental principles of the relations between force and motion were first stated by Sir Isaac Newton. They are called "Newton's Three Laws of Motion," and are as follows:

I. *All bodies continue in a state of rest, or of uniform motion in a straight line, unless acted upon by some external force that compels a change.*

II. *Every motion or change of motion is proportional to the acting force, and takes place in the direction of the straight line along which the force acts.*

III. *To every action there is always opposed an equal and contrary reaction.*

1834. In the *first law of motion* it is stated that a body once set in motion by any force, no matter how small, will move forever in a straight line, and always with the same velocity, unless acted upon by some other force which compels a change. It is not possible to actually verify this law, on account of the earth's attraction for all bodies, but from astronomical observations, we are certain that the law is true. This law is often called *the law of inertia.*

1837. In Fig. 587, a ball *e* is supported in a cup, the bottom of which is attached to the lever *o* in such a manner that a movement of *o* will swing the bottom horizontally and allow the ball to drop. Another ball *b* rests in a horizontal groove that is provided with a slit in the bottom. A swinging arm is actuated by the spring *d* in such a manner that, when drawn back as shown and then released, it will strike the lever *o* and the ball *b* at the same time. This gives *b* an impulse in a horizontal direction and swings *o* so as to allow *e* to fall.

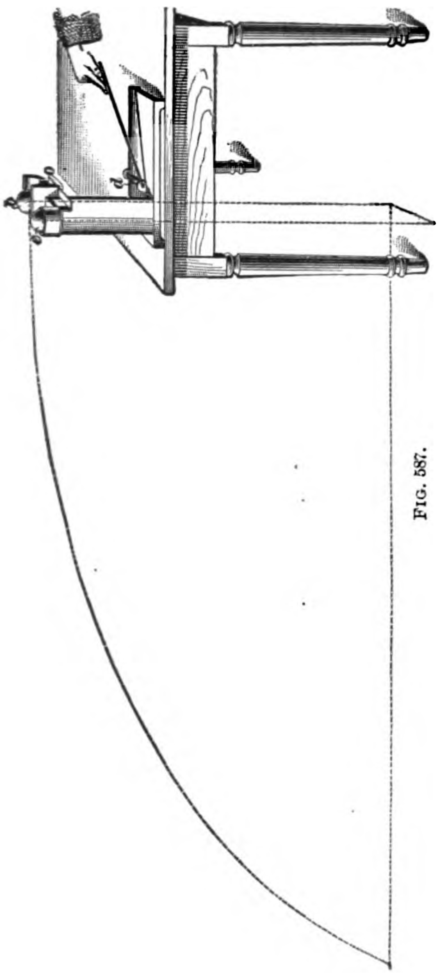


FIG. 587.

On trying the experiment, it is found that *b* follows a path shown by the curved dotted line, and reaches the floor at the same instant as *e*, which drops vertically. This shows that the force which gave the first ball its horizontal movement had no effect on the vertical force which compelled both balls to fall to the floor, the vertical force producing the same effect as if the horizontal force had not acted. The second law may also be stated as follows: *A force has the same effect in producing motion, whether it acts upon a body at* they are connected by a steel rod 1 inch in diameter, where is the center of gravity, taking the weight of a cubic inch of steel as .283 pound?

Solution.—The length of the rod $= 40 - \frac{5}{2} - \frac{10}{2} = 32\frac{1}{2}$ in. Its volume is $1^2 \times .7854 \times 32\frac{1}{2} = 25.53$ cu. in. $25.53 \times .283 = 7.22$ lb. The rod being straight, its center of gravity is in the middle at a distance of $\frac{32.5}{2} + \frac{5}{2} = 18\frac{3}{4}$ in. from the center of the smaller weight and $\frac{32.5}{2} + \frac{10}{2} = 21\frac{1}{4}$ in. from the center of the larger weight. Now, assuming the weight of the rod to be concentrated at its center of gravity, we have three weights of 10, 7.22, and 80 lb., all in a straight line, and the distances between them given, to find the center of gravity, or balancing-point, of the combination. We will first find the center of gravity of the two smaller weights by formula **93**.

$$l_1 = \frac{7.22 \times 18\frac{3}{4}}{10 + 7.22} = 7.86 \text{ in.} =$$

distance from the center of the 10-lb. weight. Considering both of the smaller weights to be concentrated at this point, we find the center of gravity of this combined weight and the large weight by the same formula:

$$40 - 7.86 = 32.14 \text{ in.} =$$

distance between the center of gravity of the two small weights and the center of gravity of the 80-lb. weight. Applying formula **93**,

$$l_1 = \frac{17.22 \times 32.14}{80 + 17.22} = 5.693 \text{ in.} =$$

distance from the center of the 80-lb. weight. Ans.

1848. Center of Gravity of a Solid.—In a body free to move, the center of gravity will lie in a vertical plumb-line

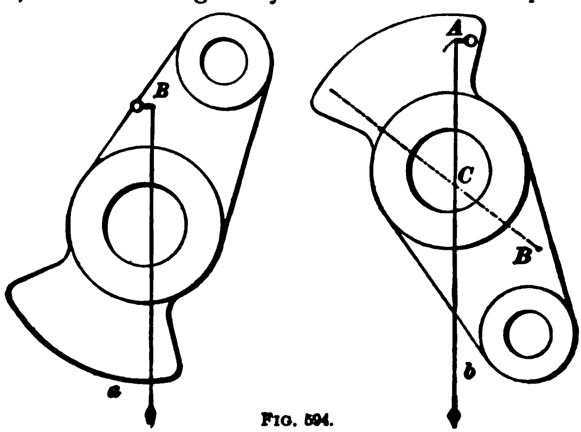


Fig. 594.

arm (or distance through which the weight moves). If any three are given, the fourth may be found by letting x represent the requirement which is to be found, and multiplying the power by the power arm and the weight by the weight arm; then, dividing the product of the two known numbers by the number by which x is multiplied, the result will be the requirement which was to be found.

EXAMPLE.—If the weight arm of a lever is 6 inches long, and the power arm is 4 feet long, how great a weight can be raised by a force of 20 pounds at the end of the power arm?

SOLUTION.—In this example, the weight is unknown; hence, representing it by x, we have, after reducing the 4 ft. to inches, $20 \times 48 = 960$ = power multiplied by the power arm, and $x \times 6$ = weight multiplied by the weight arm. Dividing the 960 by 6, the result is 160 lb., the weight. Ans.

If the distance through which the power or weight moved had been given instead of the power arm or weight arm, and it were required to find the power or weight, the process would have been exactly the same, using the given distance instead of the power arm or weight arm.

EXAMPLE.—If, in the above example, the weight had moved $2\frac{1}{2}$ inches, how far would the power have moved?

SOLUTION.—In this example, the distance through which the power moves is required. Let x represent the distance. Then, $20 \times x$ = distance multiplied by power, and $2\frac{1}{2} \times 160 = 400$ = distance multiplied by the weight. Hence, $x = \frac{400}{20} = 20$ in. = distance through which the power arm moves. Ans.

The ratio between the weights and the power is $160 \div 20 = 8$. The ratio between the distance through which the weight moves and the distance through which the power moves is $2\frac{1}{2} \div 20 = \frac{1}{8}$. This shows that while a force of 1 pound can raise a weight of 8 pounds, the 1-pound weight must move through 8 times the distance that the 8-pound weight does. It will also be noticed that the ratio of the lengths of the two arms of the lever is also 8, since $48 \div 6 = 8$.

1851. The law which governs the straight lever also governs the bent lever, but care must be taken to determine the true lengths of the lever arms, which are in every case *the perpendicular distances from the fulcrum to the line of direction of the weight or power.*

Thus, in Figs. 598 to 601, Fc in each case represents the

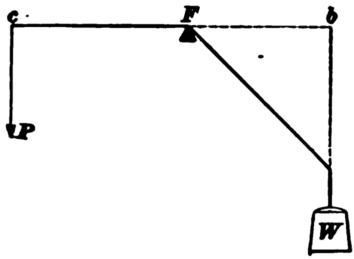


FIG. 598.

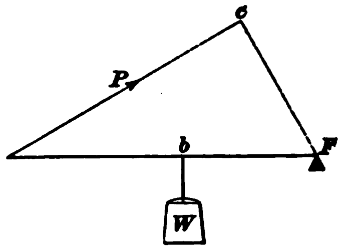


FIG. 599.

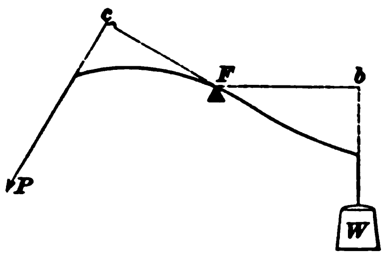


FIG. 600.

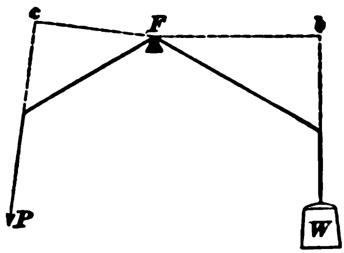


FIG. 601.

power arm, and Fb the weight arm. The following formula applies to any lever, straight or bent:

Let P = power;
W = weight;
a = perpendicular distance of line of direction of power from fulcrum = power arm;
b = perpendicular distance of line of direction of weight from fulcrum = weight arm.

Then, $$Pa = Wb. \qquad (94.)$$

1852. A **compound lever** is a series of single levers arranged in such a manner that when a power is applied to the first, it is communicated to the second, and from this to the third, and so on.

Fig. 602 shows a compound lever. It will be seen that, when a power is applied to the first lever at P, it will be communicated to the second lever at P, from this to the third lever at P, and thus raise the weight W.

The weight which the power of the first lever could raise acts as the power of the second, and the weight which this could raise through the second lever acts as the power of the third lever, and so on, no matter how many single levers make up the compound lever.

In this case, as in every other, the power multiplied by the distance through which it moves equals the weight multiplied by the distance through which it moves.

Hence, if we move the P end of the lever, say 4 inches,

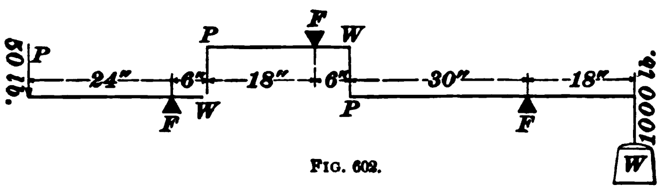


FIG. 602.

and the W end moves $\frac{1}{5}$ of an inch, we know that the ratio between P and W is the same as the ratio between 4 and $\frac{1}{5}$, that is, 1 to 20, and, hence, that 10 pounds at P would balance 200 pounds at W, without measuring the lengths of the different lever arms. If the lengths of the lever arms are known, the ratio between P and W may be readily obtained from the following rule:

Rule.—*The continued product of the power and each power arm equals the continued product of the weight and each weight arm.*

Let $a_1, a_2, a_3 \ldots = $ power arms of compound lever;
$b_1, b_2, b_3 \ldots = $ weight arms of compound lever.

Then,

$$P \times a_1 \times a_2 \times a_3 \times \ldots = W \times b_1 \times b_2 \times b_3 \times \ldots \quad (95.)$$

EXAMPLE.—If, in Fig. 602, $PF = 24$ inches, 18 inches, and 30 inches, respectively, and $WF = 6$ inches, 6 inches, and 18 inches, respectively, how great a force at P would it require to raise 1,000 pounds at W? What is the ratio between W and P?

beam, and the weight is suspended from the pulley, the other end of the cord being drawn up by the application of a force

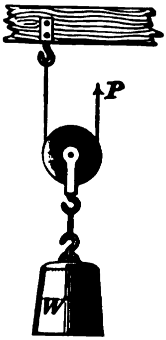


FIG. 606.

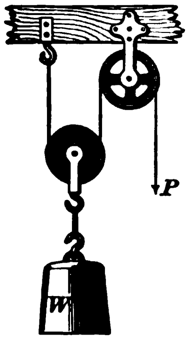


FIG. 607.

P. A little consideration will show that if *P* moves through a certain distance, say 1 foot, *W* will move through *half* that distance, or 6 inches; hence, a pull of 1 pound at *P* will lift 2 pounds at *W*.

The same would also be true if the free end of the cord were passed over a *fixed pulley*, as in Fig. 607, in which case the fixed pulley merely changes the direction in which *P* acts, so that a weight of 1 pound hung on the free end of the cord will balance 2 pounds hung from the *movable pulley*.

1857. A **combination of pulleys,** as shown in Fig. 608, is sometimes used. In this case, there are three movable and three fixed pulleys, and the amount of movement of *W*, owing to a certain movement of *P*, is readily found.

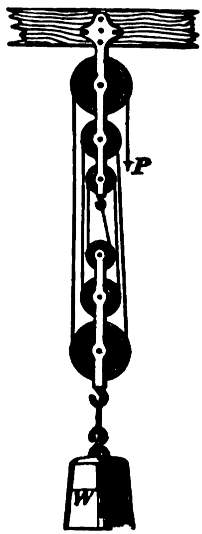


FIG. 608.

It will be noticed that there are *six parts* of the rope, not counting the free end; hence, if the movable block be lifted 1 foot, *P* remaining in the same position, there will be 1 foot of slack in each of the six parts of the rope, or *six feet* in all. Therefore, *P* would have to move 6 feet in order to take up this slack, or *P* moves 6 times as far as *W*. Hence, 1 pound at *P* will support 6 pounds at *W*, since the *power multiplied by the distance through which it moves equals the weight multiplied by the distance through which it moves.* It will also be noticed that there are three movable pulleys, and that $3 \times 2 = 6$.

1858. Law of Combination of Pulleys.—*In any combination of pulleys where one continuous rope is used, a load on the free end will balance a weight on the movable block as many times as great as itself as there are parts of the rope supporting the load—not counting the free end.*

The above law is good, whether the pulleys are side by side, as in the ordinary block and tackle, or whether they are arranged as in the figure.

EXAMPLE.—In a block and tackle having five movable pulleys, how great a force must be applied to the free end of the rope to raise 1,250 pounds?

SOLUTION.—Since there are five movable pulleys, there must be 10 parts of the rope to support them. Hence, according to the above law, a force applied to the free end will support a load 10 times as great as itself, or the force $= \frac{1,250}{10} = 125$ lb. Ans.

PULLEYS FOR TRANSMISSION OF POWER.

1859. Pulleys for the transmission of power by belts may be divided into two principal classes: (1) The solid

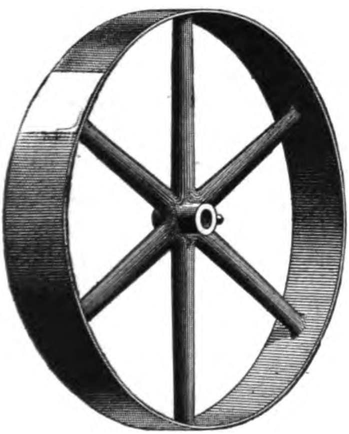


FIG. 609.

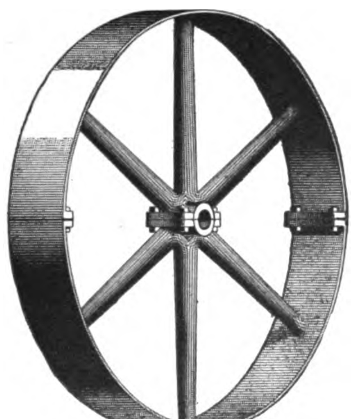


FIG. 610.

pulley shown in Fig. 609, in which the hub, arms, and rim are one entire casting. (2) The split pulley shown in Fig. 610, which is cast in halves.

teeth by formulas **102** to **108**, but if the inner or outer diameter of one gear be used, the corresponding diameter of the other gear which meshes with it must also be used.

EXAMPLES FOR PRACTICE.

1. The driving pulley makes 110 R. P. M., and is 21 inches in diameter; what should be the size of the driven in order to make 385 R. P. M.? Ans. 6 in.

2. The main shaft of a certain shop makes 120 R. P. M. It is desired to have the countershaft make 150 R. P. M. There are on hand pulleys of 16, 24, 28, 35, and 38 inches in diameter. Can two of these be used, or must a new pulley be ordered?
Ans. Use the 28-inch and the 35-inch pulley.

3. The pinion (driver) makes 174 R. P. M. and follower makes 24 R. P. M.; how many teeth must the pinion have if the follower has 87 teeth? Ans. 12 teeth.

4. If an engine fly-wheel is 66 inches in diameter and makes 160 R. P. M., what must be the diameter of the pulley on the main shaft to make 128 R. P. M.? Ans. 82½ in.

5. What is the pitch diameter of a gear whose pitch is 1¼ inches and has 28 teeth? Ans. 11.14 in.

6. How many teeth are there in a gear whose pitch is .7854 inch and which is 23 inches in diameter? Ans. 92 teeth.

7. What is the pitch of a gear whose diameter is 20.372 inches and which has 128 teeth? Ans. ½ in.

8. In a train of gears the drivers have 16, 30, 24, and 18 teeth, respectively; the followers have 12, 24, 36, and 40 teeth, respectively. If the first driver makes 80 R. P. M., how many R. P. M. will the last follower make? Ans. 40 R. P. M.

9. What horsepower can be safely transmitted by a gear whose pitch is 2½", pitch diameter 44.66", and which makes 80 R. P. M.?
Ans. 42.24 H. P.

THE INCLINED PLANE AND WEDGE.

1884. An **inclined plane** is a slope, or a flat surface, making an angle with a horizontal line.

Three cases may arise in practice with the inclined plane:

1. When the power acts parallel to the plane, as in Fig. 621.

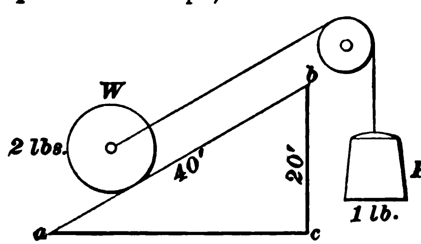


FIG. 621.

1886. The **wedge** is a movable inclined plane, and is used for moving a great weight a short distance. A common method of moving a heavy body is shown in Fig. 624.

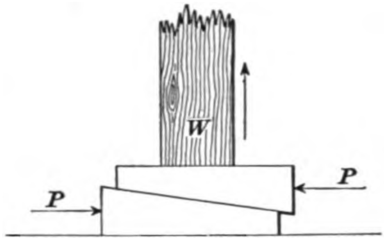


FIG. 624.

Simultaneous blows of equal force are struck on the heads of the wedges, thus raising the weight *W*. The laws for wedges are the same as for Case 2 of the inclined plane.

THE SCREW.

1887. A **screw** is a cylinder with a helical groove winding around its circumference. This helix is called the *thread* of the screw. The distance that a point on the helix is drawn back or advanced in one turn of the screw is called the *pitch* of the screw.

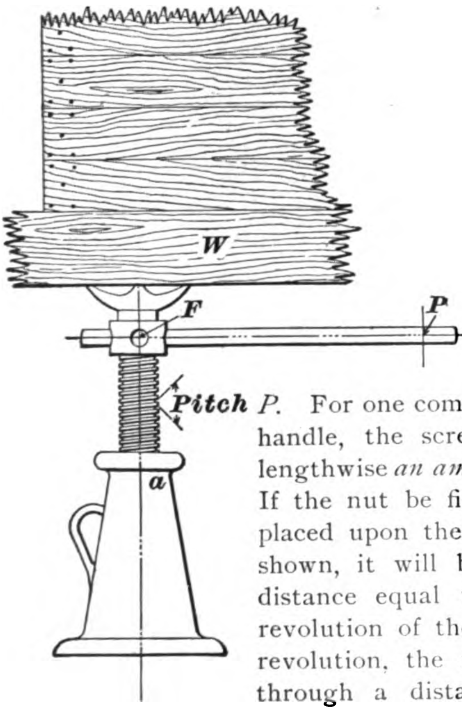


FIG. 625.

1888. The screw in Fig. 625 is turned in a *nut a*, by means of a force applied at the end of the handle. For one complete revolution of the handle, the screw will be advanced lengthwise *an amount equal to the pitch*. If the nut be fixed, and a weight be placed upon the end of the screw, as shown, it will be raised vertically a distance equal to the pitch, by one revolution of the screw. During this revolution, the force at *P* will move through a distance equal to the circumference, whose radius is PF. Hence, $W \times$ pitch of thread $= P \times$ circumference of P.

Let W = weight lifted;
P = force applied to handle;
p = pitch of screw;
R = radius of circle of force P.

Then, $$W = \frac{6.2832\,PR}{p}. \qquad (110.)$$

$$P = \frac{p\,W}{6.2832\,R}. \qquad (111.)$$

Rule.—*Represent the required force or weight by x; multiply the force by the distance from the center of the screw to the point of the handle where the force is applied; multiply this product by 2 and by 3.1416, and place the result equal to the weight multiplied by the pitch. Divide the product of the known numbers by the number or product of the numbers by which x is multiplied, and the result will be the value of x.*

Single-threaded screws of less than 1-inch pitch are generally classified by the number of threads they have in 1 inch of their length. In such cases, *one inch divided by the number of threads equals the pitch;* thus, the pitch of a screw that has 8 threads per inch is $\frac{1}{8}$, one of 32 threads per inch is $\frac{1}{32}$, etc.

EXAMPLE.—It is desired to raise a weight by means of a screw having 5 threads per inch. The force applied is 40 pounds at a distance of 14 inches from the center of the screw; how great a weight can be raised?

SOLUTION.—The pitch is $\frac{1}{5}$ inch. Using formula **110**,

$$W = \frac{6.2832 \times 40 \times 14}{\frac{1}{5}} = 17{,}592.96 \text{ lb. Ans.}$$

1889. Velocity Ratio.—The ratio of the distance that the power moves to the distance which the weight moves on account of the movement of the power is called the **velocity ratio.**

Thus, if the power is moving 12 inches while the weight is moving 1 inch, the velocity ratio is 12 to 1, or 12; that is, P moves 12 times as fast as W.

If the velocity ratio is known, the weight which any machine can raise equals the *power multiplied by the velocity ratio.* If the velocity ratio is 8.7 to 1, or 8.7, $W = 8.7 \times P$, since $W \times 1 = P \times 8.7$.

NOTE.—In all of the preceding cases, including the last, friction has been neglected.

FRICTION.

1890. Friction is the resistance that a body meets from the surface on which it moves.

1891. The **ratio** between the *resistance* to the motion of a body due to friction and the *perpendicular* pressure between the surfaces is called the **coefficient of friction.**

If a weight W, as in Fig. 626, rests upon a horizontal plane, and has a cord fastened to it passing over a pulley a,

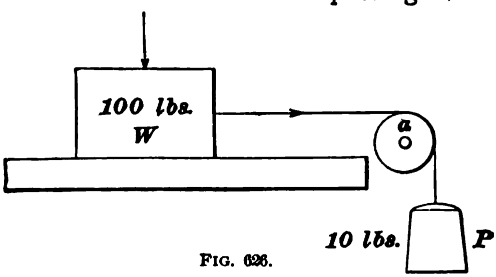


FIG. 626.

from which a weight P is suspended, then, if P is just sufficient to start W, the ratio of P to W, or $\frac{P}{W}$, is the *coefficient of friction* between W and the surface it slides upon.

The weight W is the perpendicular pressure, and P is the force necessary to overcome the resistance to the motion of W due to friction.

If $W = 100$ pounds and $P = 10$ pounds, the coefficient of friction for this particular case would be $\frac{P}{W} = \frac{10}{100} = .1$.

1892. Laws of Friction:

I. *Friction is directly proportional to the perpendicular pressure between the two surfaces in contact.*

II. *Friction is independent of the extent of the surfaces in contact when the total perpendicular pressure remains the same.*

III. *Friction increases with the roughness of the surfaces.*

IV. *Friction is greater between surfaces of the same material than between those of different materials.*

V. *Friction is greatest at the beginning of motion.*

VI. *Friction is greater between soft bodies than between hard ones.*

VII. *Rolling friction is less than sliding friction.*

VIII. *Friction is diminished by polishing or lubricating the surfaces.*

1893. Law I shows why the friction is so much greater on journals after they begin to heat than before. The heat causes the journal to expand, thus increasing the pressure between the journal and its bearing, and, consequently, increasing the friction.

Law II states that no matter how small the surface may be which presses against another, if the perpendicular pressure is the same, the friction will be the same. Therefore, large surfaces are used where possible, not to reduce the friction, but to reduce the wear and diminish the liability of heating.

For instance, if the perpendicular pressure between a journal and its bearing is 10,000 pounds, and the coefficient of friction is .2, the amount of friction is $10,000 \times .2 = 2,000$ pounds. Suppose that one-half the area of the surface of the journal is 80 square inches, then the amount of friction for each square inch of bearing is $2,000 \div 80 = 25$ pounds.

If half the area of the surface had been 160 square inches, the friction would have been the same, that is, 2,000 pounds; but the friction per square inch would have been $2,000 \div 160 = 12\frac{1}{2}$ pounds, just one-half as much as before, and the wear and liability to heat would be one-half as great also.

TABLE 31.

COEFFICIENTS OF FRICTION.

Description of Surfaces in Contact.	Disposition of Fibers.	State of the Surfaces.	Coefficient of Friction
Oak on Oak	Parallel	Dry	.48
Oak on Oak	Parallel	Soaped	.16
Wrought Iron on Oak	Parallel	Dry	.62
Wrought Iron on Oak	Parallel	Soaped	.21
Cast Iron on Oak	Parallel	Dry	.49
Cast Iron on Oak	Parallel	Soaped	.19
Wrought Iron on Cast Iron	....	Slightly Unctuous	.18
Wrought Iron on Bronze	....	Slightly Unctuous	.18
Cast Iron on Cast Iron	....	Slightly Unctuous	.15

1894. The power which is required to raise a weight, or overcome an equal resistance in any machine, is thus always *greater than this weight or resistance divided by the velocity ratio of the machine.*

Thus, if there were no friction, a machine whose velocity ratio were 5 would, by an application of a force of 100 pounds, raise a weight of 500 pounds.

Now, suppose that the friction in the machine is equivalent to the application of a force of 10 pounds; then, it would take a force of 110 pounds to raise the weight of 500 pounds.

If, in the above illustration, friction were neglected, 110 pounds $\times$ 5 = 550 pounds, or the weight that 110 pounds would raise; but, owing to the frictional resistance, it only raised 500 pounds. Therefore, we have for the ratio between the two $\frac{500}{550} = .91$. That is,

$$500 : 550 :: .91 : 1.$$

multiplied by the proper coefficient of friction, will give the friction of the cross-head on the guides.

Example.—An engine whose piston is 16 inches in diameter carries a steam pressure of 80 pounds per square inch. If the crank is 12 inches long and the connecting-rod is 66 inches long, what is the perpendicular pressure on the guides? The coefficient of friction for this case being 12%, what force will be required to overcome the friction?

Solution.—Pressure on piston $= 16^2 \times .7854 \times 80 = 16,085$ lb. $\frac{16,085 \times 12}{66} = 2,924.55$ lb. = perpendicular pressure. Ans. $2,924.55 \times .12 = 350.95$ lb. = force required to overcome the friction. Ans.

EXAMPLES FOR PRACTICE.

1. How great a force must be applied to the free end of the rope of a block and tackle which has four movable pulleys, to raise a weight of 746 pounds? Ans. 93¼ lb.

2. An inclined plane is 30 feet long and 7 feet high; what force is required to roll a barrel of flour weighing 196 pounds up the plane, friction being neglected? Ans. 45.7¼ lb.

3. The distance from the axis of a screw to the point on the handle where the force is applied is twelve inches. The screw has 8 threads per inch. What force is necessary to raise a weight of 1,248 pounds? Ans. 2.07 lb., nearly.

4. In example 3, what should be the length of the handle to raise a weight of 5,400 pounds by the application of a force of 20 pounds? Ans. 5.371 inches, nearly.

5. What is the velocity ratio (*a*) in example 3? (*b*) in example 4? Ans. { (*a*) 603, nearly. (*b*) 270. }

6. An engine-piston is 24 inches in diameter. If the steam pressure is 93 pounds per square inch; the length of the connecting-rod, 8 feet 4 inches; the length of crank 20 inches, and coefficient of friction 14%, (*a*) what is the perpendicular pressure on the guides? (*b*) the force required to overcome the friction? Ans. { (*a*) 8,414.46 lb. (*b*) 1,178 lb. }

CENTRIFUGAL FORCE.

1897. If a body be fastened to a string and whirled so as to give it a circular motion, there will be a pull on the string which will be greater or less according as the velocity increases or decreases. The cause of this pull on the string will now be explained.

R = radius in feet of circle described by center of gravity of revolving body;
N = revolutions per minute of revolving body.

Then, $F = .00034\ W R N^2$. **(112.)**

In calculating the centrifugal force of fly-wheels, it is the usual practice to consider the rim of the wheel only, and not take the arms and hub of the wheel into account. In this case, R would be taken as the *distance between the center of the rim and the center of the shaft.*

EXAMPLE.—A crank-pin weighing 65 pounds revolves in a circle whose radius is 21 inches. The number of revolutions is 180. What is the centrifugal force set up by the pin?

SOLUTION.— 21 in. = $1\frac{3}{4}$ ft. Using formula **112**,

$$F = .00034 \times 65 \times 1\tfrac{3}{4} \times 180^2 = 1{,}253.07 \text{ lb. Ans.}$$

SPECIFIC GRAVITY.

1899. The **specific gravity of a body** is the ratio between its weight and the weight of a like volume of water.

Since gases are so much lighter than water, it is usual to take the specific gravity of a gas as the ratio between the weight of a certain volume of the gas and the weight of the same volume of air.

EXAMPLE.—A cubic foot of cast iron weighs 450 pounds; what is its specific gravity, a cubic foot of water weighing 62.5 pounds?

SOLUTION.— $\frac{450}{62.5} = 7.2$. Ans.

1900. The specific gravities of different bodies are given in the tables of Specific Gravities; hence, if it is desired to know the weight of a body that can not be conveniently weighed, *calculate its cubical contents, and multiply the specific gravity of the body by the weight of a like volume of water, remembering that a cubic foot of water weighs 62.5 pounds.*

EXAMPLE.—How much will 3,214 cubic inches of cast iron weigh? Take its specific gravity as 7.21.

SOLUTION.—Since 1 cubic foot of water weighs 62.5 pounds, 3,214 cubic inches weigh $\frac{3,214}{1,728} \times 62.5 = 116.25$ pounds.

$$116.25 \times 7.21 = 838.16 \text{ pounds. Ans.}$$

EXAMPLE.—What is the weight of a cubic inch of cast iron?

SOLUTION.— $\frac{62.5}{1,728} \times 7.21 = .2608$ pound. Ans.

NOTE.—One cubic foot of pure distilled water at a temperature of 39.2° Fahrenheit weighs 62.42 pounds, but the value usually taken in making calculations is 62½ pounds.

EXAMPLE.—What is the weight in pounds of 7 cubic feet of oxygen?

SOLUTION.—One cubic foot of air weighs .08073 lb. (see table of Specific Gravities), and the specific gravity of oxygen is 1.1056 compared with air; hence, $.08073 \times 1.1056 \times 7 = .62479$ pound, nearly. Ans.

EXAMPLES FOR PRACTICE.

1. The balls of a steam-engine governor each weigh 5 pounds. If they revolve in a circle whose diameter is 14 inches at the rate of 80 revolutions per minute, what is the centrifugal force of each ball?
   Ans. 6.347 lb., nearly.

2. If a cubic foot of a certain alloy weighs 678 pounds, what is its specific gravity? Ans. 10.848.

3. What is the weight of (*a*) 12.4 cubic inches of lead? (*b*) of steel? (*c*) of aluminum?
   Ans. { (*a*) 5.0964 lb. (*b*) 3.5216 lb. (*c*) 1.116 lb.

4. The specific gravity of an alloy of lead and zinc is 8.26; what is the weight of a cubic foot? Ans. 516.25 lb.

WORK AND ENERGY.

1901. Work *is the overcoming of resistance continually occurring along the path of motion.* Mere motion is not work, but if a body in motion constantly overcomes a resistance, it does work.

1902. *The* **measure of work** *is one pound raised vertically one foot*, and is called **one foot-pound.** All work is measured by this standard. A horse going up hill does an amount of work equal to his own weight, plus the weight of the wagon and contents, plus the frictional resistances reduced to an equivalent weight, multiplied by the vertical

1904. Energy is a term used to express *the ability of an agent to do work.* Work can not be done without motion, and the work that a moving body is capable of doing in being brought to rest is called the **kinetic energy** of the body.

Kinetic energy means the actual visible energy of a body in motion. The work which a moving body is capable of doing in being brought to rest is exactly the same as the kinetic energy developed by it in falling in a vacuum through a height sufficient to give it the same velocity.

Rule.—*The kinetic energy of a moving body in foot-pounds equals its weight in pounds multiplied by the square of its velocity in feet per second, and divided by 64.32.*

Let W = weight of body in pounds;

v = velocity in feet per second;

K = kinetic energy in foot-pounds.

Then, $$K = \frac{Wv^2}{64.32}. \qquad \textbf{(113.)}$$

If a weight is raised to a certain height, a certain amount of work is done equal to the product of the weight and the vertical height. If a weight is suspended at a certain height and allowed to fall, it will do the same amount of work in foot-pounds that was required to raise the weight to the height through which it fell.

EXAMPLE.—If a body weighing 25 pounds falls from a height of 100 feet, how much work can it do?

SOLUTION.—Work = $Wh = 25 \times 100 = 2{,}500$ foot-pounds. Ans.

It requires the same amount of work or energy to stop a body in motion within a certain time as it does to give it that velocity in the same time.

EXAMPLE.—A body weighing 50 pounds has a velocity of 100 feet per second; what is its kinetic energy?

SOLUTION.—Applying formula **113**,

$$K = \frac{Wv^2}{64.32} = \frac{50 \times 100^2}{64.32} = 7{,}773.63 \text{ foot-pounds. Ans.}$$

EXAMPLE.—In the last example, how many horsepower will be required to give the body this amount of kinetic energy in 3 seconds?

SOLUTION.— 1 H. P. = 33,000 pounds raised 1 foot in 1 minute. If 7,773.63 foot-pounds of work are done in 3 seconds, in 1 second there would be done $\frac{7,773.63}{3} = 2,591.21$ foot-pounds of work. One horsepower = 33,000 ft.-lb. per min. = 33,000 ÷ 60 = 550 ft.-lb. per sec.

The number of horsepower developed will be $\frac{2,591.21}{550} = 4.71$ H. P. Ans.

1905. Potential energy *is latent energy; it is the energy which a body at rest is capable of giving out under certain conditions.*

If a stone is suspended by a string from a high tower, it has potential energy. If the string is cut, the stone will fall to the ground, and during its fall its potential energy will change into kinetic energy, so that at the instant it strikes the ground its potential energy is wholly changed into kinetic energy.

At a point equal to one-half the height of the fall, the potential and kinetic energies are equal. At the end of the first quarter, the potential energy was $\frac{3}{4}$, and the kinetic energy $\frac{1}{4}$; at the end of the third quarter, the potential energy was $\frac{1}{4}$, and the kinetic energy $\frac{3}{4}$.

A pound of coal has a certain amount of potential energy. When the coal is burned, the potential energy is liberated and changed into kinetic energy in the form of heat. The kinetic energy of the heat changes water into steam, which thus has a certain amount of potential energy. The steam acting on the piston of an engine causes it to move through a certain space, thus overcoming a resistance, changing the potential energy of the steam into kinetic energy, and thus doing work.

Potential energy, *then, is the energy stored within a body, which may be liberated and produce motion, thus generating kinetic energy, and enabling work to be done.*

1906. The principle of **conservation of energy** teaches that energy, like matter, can never be destroyed. If a clock is put in motion, the potential energy of the spring is changed into kinetic energy of motion, which turns the wheels, thus producing friction.

MECHANICS.

(PART 2.)

THE COMPOSITION OF FORCES.

1913. When two forces act upon a body at the same time but at different angles, their final result may be obtained as follows:

In Fig. 628, let A be the common ***point of application*** of the two forces, and let $A\ B$ and $A\ C$ represent the ***magnitude*** and *direction* of the forces. According to the second law of motion, the final effect of the movement due to these two forces would be the same, whether they acted singly or together. Suppose that the line $A\ B$ represents the distance that the force $A\ B$ would cause the body to move; similarly, that $A\ C$ represents the distance which the force $A\ C$ would cause the body to move when both forces were acting separately. The force $A\ B$, acting alone, would carry the body to B; if the force $A\ C$ were now to act upon the body, it would carry it along the line $B\ D$, parallel to $A\ C$, to a point D, at a distance from B equal to $A\ C$. Join C and D; then, $C\ D$ is parallel to $A\ B$, and $A\ B\ D\ C$ is a parallelogram. Draw the diagonal $A\ D$. According to the second law of motion, the body will stop at D, whether the forces act separately or together, but if they act together, the path of the body will be along $A\ D$, the diagonal of the parallelogram. Moreover, the length of the line $A\ D$ represents the *magnitude* of a force, which, acting at A in the *direction* $A\ D$, would

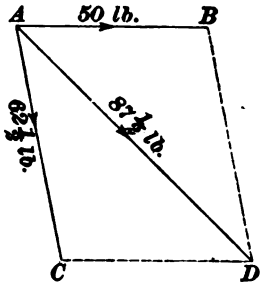


FIG. 628.

cause the body to move from A to D; in other words, $A\ D$, measured to the same scale as $A\ B$ and $A\ C$, represents in *magnitude* and *direction* the combined effect of the two forces $A\ B$ and $A\ C$.

This line $A\ D$ is called the **resultant.** Suppose that the scale used was 50 pounds to the inch; then, if $A\ B = 50$ pounds, and $A\ C = 62\frac{1}{2}$ pounds, the length of $A\ B$ would be $\frac{50}{50} = 1$ inch, and the length of $A\ C$ would be $\frac{62.5}{50} = 1\frac{1}{4}$ inches. If $A\ D$, or the *resultant*, measures $1\frac{3}{4}$ inches, its *magnitude* would be $1\frac{3}{4} \times 50 = 87\frac{1}{2}$ pounds.

Therefore, a force of $87\frac{1}{2}$ pounds acting upon a body at A in the direction $A\ D$ will produce the same result as the combined effects of a force of 50 pounds acting in the direction $A\ B$, and a force of $62\frac{1}{2}$ pounds acting in the direction $A\ C$.

1914. The above method of finding the resulting action of two forces acting upon a body at a common point is correct, whatever may be their direction and magnitudes. Hence, to find the **resultant** of two forces when their common point of application, their direction, and magnitudes are known:

Rule.—*Assume a point, and draw two lines parallel to the directions of the lines of action of the two forces. With any convenient scale, measure off from the point of intersection (common point of application) distances corresponding to the magnitudes of the respective forces, and complete the parallelogram. From the common point of application, draw the diagonal of the parallelogram; this diagonal will be the resultant, and its direction will be away from the point of application. Its magnitude should be measured with the same scale that was used to measure the two forces.*

This method is called the **graphical method of the parallelogram of forces.**

1915. The principle of the parallelogram of forces is clearly shown in Fig. 629. $A\ B\ D\ C$ is a wooden frame, jointed to allow motion at its four corners. The length

A B equals *C D*; that of *A C* equals *B D*, and the corresponding adjacent sides are in the ratio of 2 to 3. Cords pass over the pulleys *M* and *N*, carrying weights *W* and *w*, of 90 and 60 pounds. The ratio between the weights equals the ratio of the corresponding adjacent sides. A weight *V* of 120 pounds is hung from the corner *A*.

When the frame comes to rest, the sides *A B* and *A C* lie

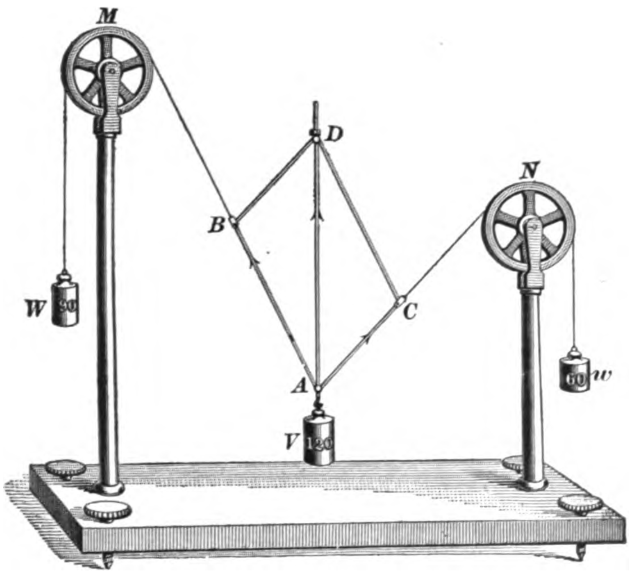


FIG. 629.

in the direction of the cords. These sides *A B* and *A C* are accurate graphic representations of the two forces acting upon the point *A*. It will be found that the diagonal *A D* is vertical, and twice as long as *A C*; hence, since *A C* represents a force of 60 pounds, *A D* will represent a force of 2×60, or 120 pounds.

Thus, we see that the line *A D* represents the *resultant* of the two forces *A B* and *A C*; in other words, it represents the resultant of the two weights *W* and *w*. This resultant is equal and opposite to the vertical force, which is due to the weight of *V*.

be the resultant; its direction will be opposite to that of the two forces.

NOTE.—When we speak of the resultant being opposed in direction to the other forces around the polygon, we mean that, starting from the point where we began to draw the polygon, and tracing each line in succession, the pencil will have the same general direction around the polygon as if passing around a circle, from left to right, or from right to left, but that the closing line or resultant must have an *opposite direction*; that is, *the two arrow-heads must point towards the point of intersection of the resultant and the last side.*

1917. EXAMPLE.—Suppose the center of a headwheel is elevated 100 feet above the center of a hoisting-drum, as shown in Fig. 631. The rope from the headwheel to the hoisting-drum makes an angle of 30° with a vertical line, and the weight of the carriage and the load to be hoisted is 5 tons. (1) What force will there be on the shaft of the headwheel? (2) In what direction will the resultant force act, or what would be the direction in which the headwheel would be thrown if its shaft should break?

SOLUTION.—In Fig. 631, *A B C* represents the rope and its direction, with one end fastened to load *C*. The other end is passed over headwheel *B*, and wound around drum *A*. Now, as the rope is held in position by drum *A*, the tension at any point is equal to load *C*. Consequently, there is a force of 5 tons acting in the direction from *B* to *A*, as indicated by the arrow, and a like force acting in the direction from *B* to *C*, as indicated by the arrow. *B C* is assumed to be vertical. If we produce the lines *A B* and *C B* to *d*, *d* is the point of application; thus, we have the point of application, magnitude, and direction of the acting forces. Now, if we use a scale 1 inch = 1 ton, and lay off from *d*, the point of application, five inches or divisions on each component, as *d* to *1'*, *1'* to *2'*, *2'* to *3'*, *3'* to *4'*, *4'* to *5'*, and *d* to *1*, *1* to *2*, *2* to *3*, *3* to *4*, *4* to *5*, each inch or division represents one ton, and, consequently, the five inches

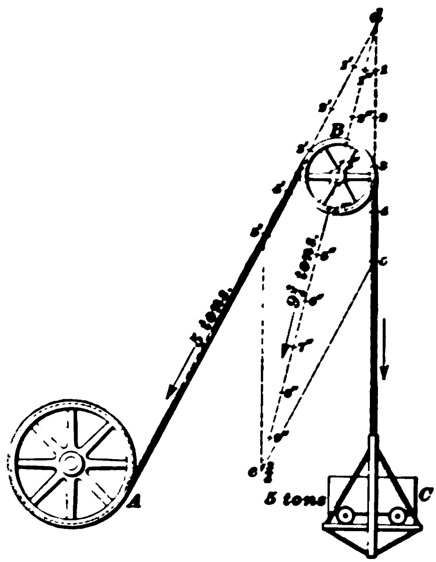


FIG. 631.

greater force. If they are equal and opposite, the *resultant* is *zero*, or one force just balances the other.

EXAMPLE.—Find the resultant of the forces whose lines of action pass through a single point, as shown in Fig. 634.

SOLUTION.—Take any convenient point *g*, and draw a line *g f*, parallel to one of the forces, say the one marked 40, making it equal in length to 40 pounds on the scale, and indicate its direction by the arrow-head. Take some other force—the one marked 37 will be convenient; the line *f e* represents this force. From the point *e*, draw a line parallel to some other force, say the one marked 29, and make it equal in magnitude and direction to it. So continue with the other forces, taking care that the general direction around the polygon is not changed. The last force drawn in the figure is *a b*, representing the force marked 25. Join the points *a* and *g*; then, *a g* is the resultant of all the forces shown in the figure. Its direction is from *g* to *a*, opposed to the general direction of the others around the polygon. It does not matter in what order the different forces are taken, the resultant will be the same in magnitude and direction, if the work is done correctly.

THE RESOLUTION OF FORCES.

1922. Since two forces can be combined to form a single resultant force, we may also treat a single force as if it was the resultant of two forces, whose action upon a body will be the same as that of a single force. Thus, in Fig. 635, the force *O A* may be resolved into two forces, *O B* and *B A*, whose directions are opposed to *O A*.

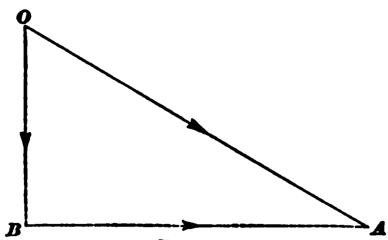


FIG. 635.

If the force *O A* acts upon a body, moving or at rest upon a horizontal plane, and the resolved force *O B* is vertical, and *B A* horizontal, *O B*, measured to the same scale as *O A*, is the magnitude of that part of *O A* which pushes the body *downwards*, while *B A* is the magnitude of that part of the force *O A* which is exerted in pushing the body in a *horizontal* direction. *O B* and *B A* are called the **components** of the force *O A*, and when these components

which must be exerted parallel to $A\ B$ in order to put the body in equilibrium, i. e., to balance the force which gravity exerts in pulling the body down the plane. If the rope r were parallel to $A\ B$, $a\ c$ would represent the weight of P; but, since r makes an angle with the plane, P will not be equal to $a\ c$. To find what the weight of P must be, draw $a\ d$ parallel to $a\ c$, but indicate it as acting in the opposite direction, or from a to d instead of from a to c. Now, treat $a\ d$ as though it were a *component* of the force acting in the rope; i. e., draw $d\ e$ perpendicular to $a\ d$, instead of perpendicular to $a\ e$. The reason for this is that if $d\ e$ were drawn perpendicular to $a\ e$, it could be resolved into components, one of which would be parallel to $a\ d$, a result which we wish to avoid; in other words, we want $d\ e$ perpendicular to the plane. The line $a\ e$, measured to the same scale as $a\ b$, will give the value of P. Measuring it, its length is .89 inch; hence, $P = .89 \times 60 = 53.4$ pounds. Ans.

To determine the perpendicular pressure against the plane, it will be noticed that $a\ b$ equals the pressure due to gravity. Since $c\ b$ and $d\ e$ are both perpendicular to $A\ B$, they are parallel, and since $d\ e$ acts in the opposite direction to $c\ b$, the actual pressure against the plane is given by the difference between $c\ b$ and $d\ e$. Making $c\ f$ equal to $d\ e$, $f\ b$ represents the perpendicular pressure against the plane when the force P ($= a\ e$) acts as shown. The length of $f\ b$ is 1.39 inches; hence, the perpendicular pressure is $1.39 \times 60 = 83.4$ pounds. Ans.

Since $c\ a$ and $a\ d$ are parallel and equal, and $c\ f$ and $d\ e$ are also parallel and equal, it follows that $a\ f$ and $a\ e$ must also be parallel and equal. Consequently, the force P might have been found by drawing $a\ f$ parallel to the direction in which the pull on the rope acts, and $b\ f$ perpendicular to the plane $A\ B$. Thus, suppose that the weight occupies the position shown by the dotted lines. Then, drawing $a\ g$ parallel to $a'\ e'$, $a\ g$ represents the weight of P, and $g\ b$ represents the perpendicular pressure of the body W against the plane. Measuring $a\ g$, its length is .79 inch; hence, $P = .79 \times 60 = 47.4$ pounds. Measuring $g\ b$, its length is 1.65 inches; hence, the perpendicular pressure $= 1.65 \times 60 = 99$ pounds.

1925. The results obtained by the graphic method can be obtained by trigonometry when the inclination of the plane and the angle the rope makes with the plane for any position of the weight W_1 are given.

Thus, $a\,c = a\,b \times \sin a\,b\,c = 120 \times \frac{20}{52} = 46.1538$ pounds.

Assuming the weight w to be in such a position that the rope r makes an angle of $30°\ 12'$ with the inclined plane, and since in the triangle $a\,d\,e$ the side $a\,d$ equals the side $c\,a$ in the triangle $a\,b\,c$, we have

$$a\,e = \frac{a\,d}{\cos e\,a\,d} = \frac{46.1538}{.86427} = 53.4 \text{ pounds. Ans.}$$

EXAMPLES FOR PRACTICE.

1. The current in a river which is ½ mile wide has a velocity of 3¾ miles an hour. (*a*) What will be the actual distance that a boat will pass over in crossing the river, if the boat is rowed at the rate of 5 miles an hour? (*b*) How far down the river will the boat have been carried when it reaches the other side? (*c*) What time will the boat require to cross the river?

Ans. { (*a*) ⅝ mi. (*b*) ⅜ mi. (*c*) 6 min.

2. What force acting parallel to a plane whose inclination is 30° will be required to support a trip of cars whose total weight is 25 tons?

Ans. 12½ tons.

3. If a driver takes a side-hitch on a trip of cars standing on the turnout, with a mule that pulls with a force of say 400 pounds in a direction making an angle of 45° with the track, what force will tend to move the trip along the track? Ans. 282.85 lb.

4. Referring to Fig. 637, what would the angle $e\,a\,d$ become, if $P = 65.271$ pounds? Ans. 45°.

5. * The two ends of a rope 7 feet long are attached to the under side of a beam at points 5 feet apart; if a weight of one hundred pounds is firmly attached to the rope at a point 4 feet from one end, what will be the tension in each segment of the rope?

Ans. { 60 lb. tension in long segment. 80 lb. tension in short segment.

6. What weight can be supported on a plane by a horizontal force of 1,521 pounds, if the ratio of the height to the base is ¾?

Ans. 2,028 lb.

7. What force is required (neglecting friction) to roll a barrel of oil weighing 300 pounds into a wagon 3 feet high by means of a plank 14 feet long resting against the wagon? Ans. 64 2/7 lb.

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* HINT.—To work this example by graphics, represent the weight by a vertical line drawn to scale; from one end of the line draw an indefinite line parallel to one of the segments of the rope, and from the other end of the line draw another indefinite line parallel to the other segment of the rope. These lines will intersect, and the distances from the point of intersection to the extremities of the vertical line will represent the tensions in the segments of the rope.

STRENGTH OF MATERIALS.

STRESSES AND STRAINS.

1926. When a force is applied to a body, it changes either its form or volume. A force, when considered with reference to the internal changes it tends to produce in any solid, is called a **stress.**

Thus, if a weight of 2 tons be held in suspension by a rod, the stress in the rod will be 2 tons. This stress is accompanied by a lengthening of the rod, which increases until the internal stress or resistance is in equilibrium with the external weight.

Stresses may be classified as follows:

Tensile, or pulling stress.

Compressive, or pushing stress.

Transverse, or bending stress.

Shearing, or cutting stress.

Torsional, or twisting stress.

1927. A **unit stress** is the amount of stress on a unit of area, and may be expressed either in pounds per square inch or in tons per square foot; or it is the load per square inch or square foot on any body.

Thus, if 10 tons are suspended by a wrought-iron bar which has an area of 5 square inches, the unit stress is 2 tons per square inch, because $\frac{10}{5} = 2$ tons.

1928. **Strain** is the deformation or change of shape of a body resulting from stress.

For example, if a rod 100 feet long is pulled in the direction of its length, and if it is lengthened 1 foot, it has a strain of $\frac{1}{100}$ of its length, or 1 per cent.

1929. **Elasticity** is the power which bodies have of returning to their original form after the external force on the body is withdrawn, providing the stress has not exceeded the elastic limit.

Consequently, we see from this that all material is

Rule.—*The load in pounds on any bar subjected to a tensile strain is equal to the minimum sectional area of the bar, multiplied by the working stress in pounds per square inch, as given in Table 32.*

That is, $W = A\,S.$ **(118.)**

Example.—A bar of good wrought iron which is 3 inches square is to be subjected to a steady tensile stress; what is the maximum load that it should carry?

Solution.—From what has been said above in regard to the materials and to the nature of the load, it will be safe in this case to use a working stress of 12,000 pounds per square inch.

Applying formula **118,** we have

$$W = 3 \times 3 \times 12{,}000 = 108{,}000 \text{ pounds. Ans.}$$

1935. Rule.—*The minimum sectional area of any bar subjected to a tensile stress is equal to the load in pounds, divided by the working stress in pounds per square inch, as given in Table 32.*

That is, $A = \frac{W}{S}.$ **(119.)**

Example.—What should be the area of a wrought-iron bar to carry a steady load of 66,000 pounds, if it is to resist a tensile stress of 12,000 pounds per square inch?

Solution.—Applying formula **119,**

$$A = \frac{66{,}000}{12{,}000} = 5.5 \text{ sq. in. Ans.}$$

1936. Rule.—*The working stress in pounds per square inch is equal to the load in pounds divided by the minimum sectional area of the bar.*

That is, $S = \frac{W}{A}.$ **(120.)**

Example.—A bar of wrought iron 3 inches square, subjected to tensile stress, carries a load of 86,400 pounds; what is the stress per square inch?

Solution.—Applying formula **120,**

$$S = \frac{86{,}400}{3 \times 3} = 9{,}600 \text{ lb. per sq. in. Ans.}$$

carried by a steel wire rope; what should be the minimum circumference of the rope?

SOLUTION.—Applying formula **126** as modified by the rule,

$$C = .0316\sqrt{10{,}485} = 3.24 \text{ inches. Ans.}$$

EXAMPLES FOR PRACTICE.

1. What should be the diameter of a steel piston-rod of a steam-engine to resist tension, if the piston is 19 inches in diameter and the pressure is 85 pounds per sq. in.? Ans. 2¼ in., nearly.

2. What safe load will a cast-iron bar of rectangular cross-section 7½ inches by 3½ inches support if subjected to shocks? The bar is in tension. Ans. 39,375 lb.

3. What is the stress per square inch on a piece of timber 8 inches square, which is subjected to a steady pull of 60,000 pounds? Ans. 937.5 lb. per sq. in.

4. What should be the safe load for a close-link wrought-iron chain whose links are made from ⅞-inch iron? Ans. 9,187.5 lb.

5. What safe load may a hemp rope carry whose circumference is 4 inches? Ans. 1,600 lb.

6. What should be the allowable working load for a steel wire rope whose circumference is 3¾ inches? Ans. 14,062.5 lb.

7. What should be the circumference of an iron wire rope to support a load of 20,000 pounds? Ans. 5¾ in., nearly.

CRUSHING STRENGTH OF MATERIALS.

1947. The crushing strength of any material is the resistance offered by its fibers to being pushed together.

If a bar is long compared with its cross dimensions, any slight disturbance from uniformity will cause it to bend sideways under the compressive force, and we have, then, not only compression, but compression compounded with bending.

To obtain only compression, the length of a rod should not be more than five times greater than its least diameter, or its least thickness when it is a rectangular rod.

Experimental tests on pillars have shown that their strengths are approximately inversely proportional to the squares of their lengths. That is, if there are two pillars of the same material, having the same cross-section, but one is twice as long as the other, the long one will sustain only about one-quarter the load of the short one.

1948. Attention should be given to the ends of pillars, as their shape has great influence upon their strength. In Fig. 638 are shown three pillars with different shaped ends.

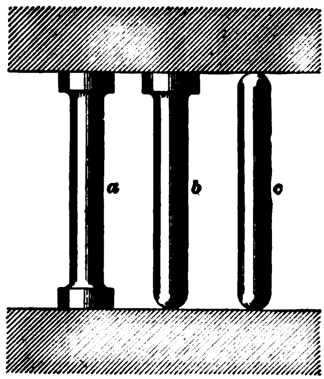


FIG. 638.

It has been proved by the aid of higher mathematics that, theoretically, a pillar having flat or fixed ends, as shown at *a*, is four times as strong as one that has round or movable ends, as shown at *c*, and one and seven-ninths times as strong as one having one flat and one round end, as shown at *b*; *b* is thus two and one-fourth times as strong as *c*. It has also been found that if three pillars, *a*, *b*, *c*, which have the same cross-section, are to carry the same load and be of equal strength, their lengths must be as the numbers 2, 1½, and 1, respectively.

In practice, however, the ends of the pillars *b* and *c* are not generally made as shown by the figure, but have holes at their ends into which pins are fitted which are fastened to some other piece; as, for example, a connecting-rod of an engine. In such cases, it has been found that *a* is two times as strong as *c*, and that *b* is one and one-half times as strong as *c*. That is, in actual practice, a column fixed as at *c* is really one-half as strong as one fixed as at *a*, instead of being only one-quarter as strong, as given above.

Green or wet timber has only one-half the strength of dry and seasoned timber; consequently, its crushing strength is only one-half of that given in the table below.

1949. In Table 33 is given the mean crushing strength of some short specimens of materials in tons (of 2,000 pounds) per square inch.

TABLE 33.

Materials.	Crushing Strength in Tons per Square Inch.
Cast Iron..................	40
Wrought Iron............	18
Mild Steel...............	26
Cast Copper.............	5
Cast Brass	4.5
Timber (Dry)	3.5
Brick......................	1
Stone	3

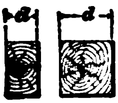
STRENGTH OF PILLARS.

1950. The following formula is applicable to pillars which are commonly used in practice, the lengths of which are about from 10 to 40 times their least diameter, or, if rectangular, their least thickness as indicated by d:

Let C = crushing strength in tons per square inch of a short specimen of the material as given in Table 33;
S = sectional area in square inches;
L = length in inches;
d = least thickness of rectangular pillar, or diameter of round pillar in inches;
W = breaking load in tons;
A = the area of the two flanges;
B = the area of the web;
a = a constant for the particular form of cross-section and material of which the pillar is made; its value is given in Tables 34 to 36 for such cross-sections as are given in the first column of those tables, and for such material as is mentioned at the top of the tables.

TABLE 36.

WOODEN PILLARS.

Cross-section of Pillar.	When Both Ends of the Pillar are Flat or Fixed.	When One End of the Pillar is Flat or Fixed, and the Other Round or Movable.	When Both Ends of the Pillar are Round or Movable.
 Round.	187.5	125.00	93.75
 Square or Rectangle.	250.0	166.66	125.00
 Hollow Square Made of Boards.	500.0	333.33	250.00

The result obtained by the formula must be divided by 6 to get the safe working load.

NOTE.—If the length of the pillar is given in feet, be sure to reduce it to inches before substituting in the formula.

EXAMPLE.—A wooden pillar 6 inches square and 144 inches long is fixed at both ends; what load will it sustain with safety?

SOLUTION.—Using formula **127**, we have

$$W = \frac{3.5 \times 6 \times 6}{\frac{144 \times 144}{250 \times 6 \times 6} + 1} = 38.14 \text{ tons, nearly.}$$

Which, divided by 6, gives $\frac{38.14}{6} = 6.357$ tons, or the load it is capable of sustaining with safety. Ans.

EXAMPLE.—A wrought-iron pillar 4 inches in diameter and 60 inches long is fixed at one end and movable at the other; what load will it sustain with safety?

SOLUTION.—Using formula **127**,

$$W = \frac{18 \times 4 \times 4 \times .7854}{\frac{60 \times 60}{1,500 \times 4 \times 4} + 1} = 196.69 \text{ tons.}$$

Which, divided by 6, gives $\frac{196.69}{6} = 32.78$ tons, nearly, or the load it is capable of sustaining with safety. Ans.

EXAMPLE.—A cast-iron pillar is 20 feet long and its cross-section is a cross with equal arms which are 1 inch thick and 10 inches long. (See dimension *d*, Table 35.) The two ends of the pillar are movable. What load will the column safely sustain?

SOLUTION.—Area of cross-section is equal to $(10 \times 1) + 2(4.5 \times 1) =$ 19 square inches; 20 feet are equal to 240 inches.

Now, applying formula **127**,

$$W = \frac{40 \times 19}{\frac{240 \times 240}{93.75 \times 10 \times 10} + 1} = 106.38 \text{ tons.}$$

Which, divided by 6, gives $\frac{106.38}{6} = 17.73$ tons, the load it is capable of sustaining with safety. Ans.

When using formula **127**, first obtain the value of *C* from Table 33. Next, calculate the area of the cross-section of the pillar. Then, find the value of *a* from one of the tables. Finally, be sure that the length of the pillar has been reduced to inches before substituting in the formula.

EXAMPLES FOR PRACTICE.

1. What load may be safely carried by a hollow cylindrical cast-iron pillar 20 ft. long, inside diameter 8", and outside diameter 10"? Both ends of the pillar are fixed. Ans. 93.13 tons.

2. A rectangular wooden column is 14 ft. long, and has one end rounded; if the cross-section is 12" × 8", what load will be required to break it? Ans. 92.15 tons.

3. A solid wrought-iron column, which has both ends movable, is 3" in diameter and 8 ft. long; what load will it safely support? Ans. 11.1 tons.

TRANSVERSE STRENGTH OF MATERIALS.

1952. The transverse strength of any material is the resistance offered by its fibers to being broken by bending. As, for example, when a beam, bar, rod, etc., which is supported at its ends, is broken by a force applied between its supports.

The transverse strength of any beam, bar, rod, etc., is proportional to the product of the square of its depth multiplied by its width; consequently, it is more economical to increase the depth than the width.

TABLE 37.

CONSTANTS FOR TRANSVERSE STRENGTH.

Materials.	Safe Transverse Strength in Pounds.	Materials.	Safe Transverse Strength in Pounds.
METALS.		WOODS.	
Cast Iron	100	Birch	35
Wrought Iron	150	Elm	25
Structural Steel	160	Ash	45
Copper	50	Beech	30
Brass	55	Hickory	50
		Maple	60
		Oak (American)	45
		Pine (Pitch)	40
		Pine (White)	30

1953. A **cantilever** is a beam, bar, rod, etc., fixed at one end and subjected to a transverse stress, as shown in Fig. 639. It has a tendency to overthrow the wall or structure to which it is attached.

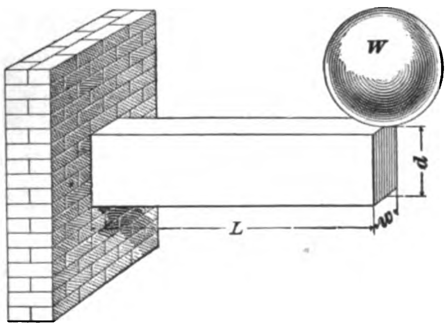


FIG. 639.

The strength of a cantilever varies inversely as the distance of the load from the section acted upon; and the stress upon any section varies directly as the distance of the load from that section thickness of the plate multiplied by the circumference of a circle having the same diameter as the punched hole. For, if the plate were cut through one of the diameters of the punched hole and the two semicircles were straightened out, the punched surface would be a rectangle, which would have a length equal to the circumference of a circle whose diameter was equal to that of the hole, and a breadth equal to the thickness of the plate. In this case, the area $= \frac{5}{8} \times 3.1416 \times \frac{1}{2} = .98175$ sq. in. Table 38 gives the ultimate shearing strength of steel as 60,000 lb. per sq. in. Hence, the total force required is $.98175 \times 60,000 = 58,905$ lb. Ans.

EXAMPLES FOR PRACTICE.

1. What is the greatest load that can be safely carried by a steel rectangular cantilever at its extreme end, if the bar is 2″ wide, 3″ deep, and 2 ft. 6″ long? Ans. 1,152 lb.

2. What is the greatest uniform load that can be safely carried by a white pine girder 6″ wide, 8″ deep, 16 ft. long, and supported at its ends? Ans. 5,760 lb.

3. A cast-iron bar $1\frac{3}{4}$″ in diameter and 5 ft. 3″ long is supported at its ends; what load will it safely sustain in the middle? Ans. 245 lb.

4. What force is required to punch a $1\frac{1}{4}$″ hole through a wrought-iron plate $\frac{7}{16}$″ thick? Ans. 68,723 lb.

5. What force is required to cut off the end of a cast-iron bar whose diameter is $2\frac{1}{2}$″? Ans. 88,357 lb.

LINE SHAFTING.

1964. A line of shafting is one continuous run, or length, composed of lengths of shafts joined together by couplings.

The **main line** of shafting is that which receives the power from the engine or motor, and distributes it to the other lines of shafting, or to the various machines to be driven.

Line shafting is supported by hangers, which are brackets provided with bearings bolted either to the walls, posts, ceilings, or floors of the building. Short lengths of shafting called **countershafts** are provided to effect changes of speed, and to enable the machinery to be stopped or started.

Shafting is usually made cylindrically true, either by a special rolling process known as **cold-rolled shafting**, or be considered to be the kinetic energy of the molecules composing the body. A small iron rod may be heated to whiteness and yet possess a very small quantity of heat. Its temperature is very high, which simply indicates that the molecules of the rod are vibrating with an extremely high velocity.

1974. Temperature is measured by an instrument called the thermometer, which is so familiar as to scarcely need description. It consists of a thin glass tube, at one end of which is a bulb filled with mercury. Upon being heated, the mercury expands in proportion to its temperature. Thermometers are graduated in different ways. In the Fahrenheit thermometer, which is generally used in this country, the point where the mercury stands when the instrument is placed in melting ice is marked 32°. The point indicated by the mercury when the thermometer is placed in water boiling in open air at the level of the sea is marked 212°. The tube between these two points is divided into 180 equal parts called degrees.

1975. Effects of Heat.—Suppose we take a vessel filled with some substance, say water. Let the vessel be a cylinder fitted with a piston, as shown in Fig. 647. The water is, say, at the freezing-point, and the millions of molecules composing the water are moving to and fro with a comparatively small velocity. Suppose the vessel is placed in a fire or furnace. Heat is communicated to the molecules of water, and they begin to move faster and faster. That is, their kinetic energy increases, and if a thermometer were inserted in the vessel it would be found that the temperature of the water rises. Consequently, one effect of heat is to raise the temperature of the body to which it is applied. But, after reaching a certain temperature, the molecules of the water not only move faster, but they move

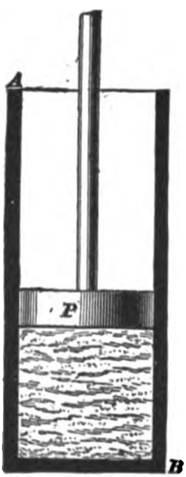


FIG. 647.

farther from each other, and their paths are longer. It is plain that if the molecules are farther apart than they were originally, the whole body of them must take up more space. In other words, after reaching a certain temperature, the water expands as heat is added. Hence, another effect of heat is to expand bodies to which it is applied. Common examples of the expansion of bodies by heat are seen in the setting of tires, the expansion of the rails of a railway in summer, etc.

1976. The heat supplied to the vessel of water has so far done three things: (1) Raised the temperature of the water, and thus increased the kinetic energy of the molecules. Let the amount of heat expended for this purpose be denoted by S. (2) A certain quantity of heat has been used in expanding the water; that is, in pushing its molecules farther apart against the force of cohesion. Denote the amount of heat so expended by I. (3) Since the water expands, it must raise the piston P against the pressure of the atmosphere, and, consequently, more heat must be used to expand the water than would be required if there were no pressure on the upper side of the piston. Call this extra quantity of heat W.

If we denote by Q the total heat given up to the vessel of water, we have

$$Q = S + I + W.$$

Ordinarily, the greater part of the heat given to a body is spent in raising its temperature, and but little is used in expanding the body. That is, the quantity S is nearly equal to the quantity Q, while the quantities I and W are nearly nothing.

1977. Suppose that the piston is removed from the cylinder of Fig. 647, and a thermometer is inserted. As the vessel becomes more and more heated, the temperature indicated by the thermometer will rise until it reaches 212°. So far most of the heat has been used to raise the temperature of the water. But now, no matter how much heat is added to the water, the thermometer stands at 212°, and

1980. **Relation Between Heat and Work.**—Suppose that, in the experiment shown in Fig. 647, the piston had been allowed to remain in the cylinder while the water was being changed to steam. Steam at 212° occupies nearly 1,700 times the space that the water originally occupied. Hence, the piston would be lifted in the cylinder to give room for the steam which was being formed. But to raise the piston requires work. Here, then, is an example of *work being performed by heat.* On the other hand, work will produce heat. If two blocks of wood are rubbed briskly together, they will become warm, and may even ignite. The work of friction causes the journals and bearings of fast-running machines to heat. A small iron rod may be heated to redness by pounding it on an anvil.

1981. Since work may be changed into heat, and heat into work, it seems probable that there is some fixed ratio between the unit of heat (B. T. U.) and the unit of work, the foot-pound. By a careful series of experiments, Dr. Joule, of England, discovered this ratio. He found that one B. T. U. is equal to 772 foot-pounds; later and more careful experiments show that 778 foot-pounds is more nearly correct. This number, 778 foot-pounds, is called the **mechanical equivalent** of one B. T. U.

We have, then, the following important law: *Heat may be changed to work, or work to heat; 778 foot-pounds of work are required to produce 1 B. T. U., and, conversely, the expenditure of 1 B. T. U. produces 778 foot-pounds of work.*

EXAMPLE 1.—The burning of a pound of coal gives out sufficient heat to raise 14,000 pounds of water from 62° to 63°. If all this heat is wholly utilized, how high will it lift a weight of 700 pounds?

SOLUTION.—Since 1 B. T. U. raises a pound of water from 62° to 63°, it requires 14,000 B. T. U. to raise 14,000 lb. of water from 62° to 63°. Hence, the burning of the pound of coal gives out 14,000 B. T. U. One B. T. U. is equivalent to 778 foot-pounds; hence, 14,000 B. T. U. are equivalent to $14,000 \times 778 = 10,892,000$ foot-pounds. Then, the height to which the weight can be raised is $10,892,000 \div 700 = 15,560$ feet. Ans.

EXAMPLE 2.—A cannon-ball weighing 60 pounds moves with a

EXAMPLE 1.—It is found that to raise the temperature of 20 pounds of iron from 62° to 63° requires 2.276 B. T. U. What is the specific heat of iron?

SOLUTION.—To raise 20 pounds of water from 62° to 63° requires 20 B. T. U. The specific heat of the iron is, according to the above definition, the ratio between the quantities of heat required to warm the iron and the water, respectively, through 1 degree; that is, it is the ratio 2.276 : 20 = 2.276 ÷ 20 = .1138. Ans.

EXAMPLE 2.—The specific heat of silver is .057. How many B. T. U. are required to raise 22 pounds of silver from 50° to 60°?

SOLUTION.—To raise the temperature of a pound of water 1 degree requires 1 B. T. U. Since the specific heat of silver is .057, only .057 B. T. U. is required to raise 1 pound of silver 1 degree. Hence, to raise 22 pounds of silver 10 degrees must require .057 × 22 × 10 = 12.54 B. T. U. Ans.

1983. Rule.—*To find the number of B. T. U. required to raise the temperature of a body a given number of degrees, multiply the specific heat of the body by its weight in pounds and by the number of degrees.*

Denote the number of B. T. U. required by U; the specific heat by c; the weight by W, and let t and t_1 be the temperatures before and after the heat is applied, respectively.

Then, $$U = c\,W\,(t_1 - t). \qquad \textbf{(136.)}$$

The specific heats of some of the more common substances are given in the following table:

TABLE 41.

Substance.	Sp. Heat.	Substance.	Sp. Heat.
Water	1.0000	Ice	.5040
Sulphur	.2026	Steam (superheated)	.4805
Iron	.1138	Air	.2375
Copper	.0951	Oxygen	.2175
Silver	.0570	Hydrogen	3.4090
Tin	.0562	Nitrogen	.2438
Mercury	.0333	Carbon monoxide	.2479
Lead	.0314	Carbon dioxide	.2170

steam into water at 212° liberates 966 B. T. U. This principle is applied in heating buildings by steam. The steam passes through the radiators and condenses. The latent heat thus set free warms the building.

1987. Temperature of Mixtures.—It is often desirable to calculate the final temperature of a mixture of different substances at different temperatures. The following law is to be observed in such cases: *The quantity of heat in a mixture is the same as the quantity of heat contained in the substances before being combined.* If two substances of different temperatures are placed together, they both finally attain the same temperature; the heat lost by the one in coming from a higher to a lower temperature is gained by the other in passing from a lower to a higher temperature.

Rule.—*To find the temperature of a mixture of several substances, multiply together the weight, specific heat, and temperature of each substance separately, and add the products. Next, multiply together the weight and specific heat of each of the substances separately, and add these products. Divide the former sum by the latter. The result will be the temperature of the mixture.*

Let $w, w_1, w_2 \ldots\ldots$ = weights of the several substances, respectively;
$c, c_1, c_2 \ldots\ldots$ = specific heats of the substances, respectively;
$t, t_1, t_2 \ldots\ldots$ = temperatures of the substances, respectively;
T = final temperature of mixture.

Then,
$$T = \frac{w\,c\,t + w_1 c_1 t_1 + w_2 c_2 t_2 + \ldots\ldots}{w\,c + w_1 c_1 + w_2 c_2 + \ldots\ldots}. \qquad (137.)$$

EXAMPLE.— 15 pounds of water at 42° and 30 pounds of mercury at 70° are placed in the same vessel, and a ball of lead weighing 19 pounds and having a temperature of 110° is immersed in the mixture. What will be the final temperature of the contents?

SOLUTION.—Applying formula **137**,

$$T = \frac{15 \times 1 \times 42 + 30 \times .0333 \times 70 + 19 \times .0314 \times 110}{15 \times 1 + 30 \times .0333 \times 19 \times .0314} = 46.13°. \text{ Ans.}$$

EXAMPLES FOR PRACTICE.

1. A body weighing 143 pounds falls 62 feet. If the energy of the body at the end of the fall be changed into heat, how many B. T. U. will be developed? Ans. 11.39 B. T. U.

2. An expenditure of 210 B. T. U. per minute will develop how many horsepower? Ans. 4.95 H. P.

3. Supposing ⅙ of the total heat of the coal to be used in doing work, how many pounds of coal must be burned per hour to run a 40 horsepower engine? Each pound of the coal gives out 13,500 B. T. U. Ans. 52.8 lb.

4. From what height must a block of ice fall, that the heat developed by its collision with the earth may be just enough to melt it, supposing that all of the energy gained during the fall is converted into heat? Ans. 112,032 feet.

5. A bar of iron weighing 20 pounds and having a temperature of 350° is plunged into a tank containing 130 pounds of water at 55°. To what temperature will the water be raised? Ans. 60°.

6. How many pounds of ice at 32° can be melted by 3 pounds of steam at 212°? Ans. 23.875 lb.

SUGGESTION.—Each pound of ice requires 144 B. T. U. to melt it; each pound of steam in changing to water at 32° gives up 1,146 B. T. U. (See Art. **1999.**)

7. How many B. T. U. are required to raise the temperature of 26 pounds of copper from 57° to 93°? Ans. 89.1 B. T. U.

STEAM.

PRELIMINARY IDEAS.

1988. Steam is *water vapor;* that is, it is *water* changed into a *gaseous state* by the application of *heat.*

The process of changing water (or other liquid) into vapor by means of heat is called **ebullition,** or **boiling.**

1989. When a vessel containing water is placed in contact with a flame of fire, the air which is generally contained in the water is first driven off and escapes from the surface without noise. The molecules of the water which are in contact with the part of the vessel nearest the fire receive heat first, and begin to move more and more rapidly until, finally, the cohesion between them is overcome, and they rise into the main body of water. At last, the whole mass of water becomes heated through, and the molecules are then able to rise through the body of the water, overcome the pressure on the surface of the water, and escape in the form of a gas. Then the water boils.

1990. It is plain that if the pressure on the surface of the water is increased, it will take more work to force the molecules to the surface against the increased pressure. That is, more heat must be expended upon the water to make it boil, and, therefore, the boiling-point will be raised. We have seen that when water boils in open air, exposed, therefore, to the atmospheric pressure of 14.7 lb. per sq. in., the water boils when it reaches a temperature of 212°. If the pressure on the surface is increased to say 32 lb. per sq. in., the water will not boil until it reaches a temperature of 254°. On the other hand, if the pressure is lowered to 6 lb. per sq. in., the water boils when it reaches 170°. Hence, we have the following law:

An increase of pressure on the surface of a liquid raises the temperature at which it boils; a decrease of pressure lowers the temperature at which it boils.

1991. When steam is in contact with the water from which it is generated, it is called **saturated steam.** This is the condition of steam in a boiler. According to the law just given, the temperature of saturated steam depends upon the pressure only. When the steam in a boiler shows a gauge pressure of 60 pounds, its temperature *must be* 307°. A thermometer placed in a boiler could be used to tell the pressure of the steam. It would be even more accurate (though not as convenient) than a steam-gauge.

1992. Steam, if not in contact with water, may be heated like air or any other gas until its temperature is higher than the boiling-point. For instance, let a quantity of water be placed in a cylinder as shown at *a*, Fig. 648. Suppose, for convenience, that the area of the cylinder is 100 sq. in.; then, the pressure of the atmosphere upon the piston is $14.69 \times 100 = 1,469$ lb. The number 14.69 is a little more exact than 14.7.

the form of spray, and when such fine spray has been once entrained or carried up with the steam, it does not readily settle against the rising current of the new steam that is constantly being formed. Steam has been known to hold 16 times its own weight of water in suspension, or to be 1,600 per cent. moist; in the usual practice, however, the priming of steam-boilers falls within the range of from 5 to 15 per cent.

1995. Gauge and Absolute Pressures.—It has been shown that the pressure of the atmosphere is 14.7 pounds per square inch above vacuum. Ordinary gauges register pressures above atmosphere only. Thus, if the steam-gauge of a boiler shows 80 pounds pressure, it indicates that the pressure of the steam in the boiler is 80 pounds per square inch greater than the pressure of the atmosphere. To find the pressure of the steam above vacuum, we must, therefore, add 14.7 to the gauge-reading; thus, $80 + 14.7 = 94.7$. The pressures indicated by the gauge are called **gauge pressures**; pressures above vacuum are called **absolute pressures.** To obtain the absolute pressure, add 14.7 to the gauge pressure.

PRESSURE AND TEMPERATURE OF STEAM.

1996. Having given the gauge pressure or the pressure above the atmosphere in a boiler, to determine the temperature of the steam and water within the boiler:

Rule.—*To 199 add 14 times the square root of the pressure. The result will be in Fahrenheit degrees.*

Let t = temperature of steam;
p = gauge pressure of steam.

Then, $$t = 199 + 14\sqrt{p}. \qquad \textbf{(138.)}$$

EXAMPLE.—The pressure in a boiler is 81 pounds per square inch above the atmosphere, as shown by the steam-gauge; what is the temperature of the steam in the boiler?

SOLUTION.— $t = 199 + 14\sqrt{81} = 325°$ Fahrenheit. Ans.

1997. Having given the temperature of the steam and water within a boiler in Fahrenheit degrees, to determine the pressure within the boiler:

Rule.—*Subtract 199 from the temperature, and divide their difference by 14. The square of this quotient will be the pressure within the boiler in pounds per square inch above the atmosphere;*

or, $$p = \left(\frac{t - 199}{14}\right)^2. \qquad \textbf{(139.)}$$

Example.—The temperature of the steam within a boiler is 325° F.; what is the pressure in the boiler?

Solution.— $p = \left(\frac{325° - 199}{14}\right)^2 = 81$ pounds per square inch above atmospheric pressure, or $81 + 14.7 = 95.7$ pounds per square inch above a vacuum. Ans.

PROPERTIES OF STEAM.

1998. The **total heat of vaporization** is the number of heat units required to change a pound of water at 32° F. to steam of the given temperature and pressure.

1999. Having given the temperature of the steam within a boiler in Fahrenheit degrees, to determine the total heat of vaporization of 1 pound of the saturated steam in the boiler from water at 32° F.:

Rule.—*Add 1,081.4 to the product of the given temperature of the steam and .305. The result will be the number of British thermal units required to convert 1 pound of water at 32° F. into 1 pound of steam at the given temperature.*

Let H = total heat of vaporization in B. T. U.;

t = temperature of steam.

Then, $$H = 1{,}081.4 + .305\,t. \qquad \textbf{(140.)}$$

Example.—What is the total heat of vaporization of one pound of saturated steam at 325° F.?

Solution.— $H = 1{,}081.4 + .305 \times 325 = 1{,}180.5$ B. T. U. Ans.

2000. The **temperature** of saturated steam does not increase by equal increments for equal advances in pressure, but rises in a decreasing ratio. For example, at in the proportion of 1 pound of oxygen to 3.35 pounds of nitrogen; or, by volume, 1 cubic foot of oxygen to 3.76 cubic feet of nitrogen. Therefore, for every pound of oxygen employed in combustion, 4.35 pounds of air must be supplied, or for every cubic foot of oxygen, 4.76 cubic feet of air must be supplied. Nitrogen, however, takes no part in combustion, and, whenever present, passes off as a free gas, heated up to the temperature of the other gases with which it is mixed.

The volume of 1 pound of
  Air at 62° F. is..................13.14 cubic feet.
  Oxygen at 62° F. is..............11.89 cubic feet.
  Nitrogen at 62° F. is.............13.50 cubic feet.

2005. **Fuels** are those forms of matter which are chiefly composed of the combustible elements, *carbon* and *hydrogen*. Coal, coke, wood, and petroleum are examples of fuels, but of these, coal is by far the most generally used in the furnaces of boilers for the production of steam.

2006. The temperature at which a combustible element or fuel takes fire, when brought into the presence of oxygen or air, differs for each substance considered, although it is a constant for any one form of matter. For example, sodium ignites and enters into chemical combination with the air at ordinary temperatures, while, in order to light an illuminating gas jet with a piece of heated iron, the iron would have to be heated to an orange color, or a temperature of about 2,000° F.

2007. Hydrogen, in whatever form it may appear, will always separate and combine with *oxygen*, when ignited, in the proportion of 1 pound of hydrogen to 8 pounds of oxygen to produce steam, in which form it will pass off and condense into 9 pounds of water; during the time it is being completely burned, 62,032 B. T. U. will be generated.

2008. The combustion of *carbon*, in like manner, is always complete at first; that is to say, 1 pound of carbon combines with 2.66 pounds of oxygen to form 3.66 pounds

TABLE 42.

One Pound of Combustible.	Theoretical Weight of Gas, in Pounds, Required to Effect the Complete Combustion of One Pound of Combustible.		Actual Weight of Air, in Pounds, Required to Effect the Complete Combustion of One Pound of Combustible.		Total Heat of Combustion of One Pound of Combustible in B. T. U.	The Equivalent of the Total Heat of Combustion, Expressed in the Number of Pounds of Water under Atmospheric Pressure it would Evaporate.	
	Oxygen.	Air.	With Chimney Draft, and Initial Temperature of Air at 62° F.	With Forced Draft at 62° F., and Waste Gases at 320° F.		From 62° F. and at 212° F.	From and at 212° F.
	1	2	3	4	5	6	7
Hydrogen	8.00	34.8	70	47	62,032	55.6	64.0
Carbon (completely burned)	2.66	11.6	22	15	14,500	13	15
Coal (of average composition)	2.46	10.7	21	14	14,133	12.67	14.63
Coke	2.50	10.9	22	15	13,550	12.14	14.02
Wood (average kiln-dried)	1.40	6.10	12	18	7,792	6.98	8.07
Petroleum	3.54	11.9	31	21	20,408	18.83	21.18

(*b*) The total heat of combustion of 1 pound of coal is 14,133 B. T. U. (see column 5, Table 42); therefore, 453.6 × 14,133=6,410,728.8 B. T. U. will be generated in the furnace per hour. Ans.

(*c*) From column 7 of Table 42, we find the equivalent evaporation of 1 pound of coal to be 14.63 pounds of water from and at 212° F.; therefore, 453.6 pounds of coal would evaporate 453.6 × 14.63 = 6,636.168 pounds of water per hour. Ans.

STEAM-BOILERS.

TYPES OF BOILERS.

2010. A **steam-boiler** is an apparatus for the production of steam under pressure by the expenditure of the heat energy stored in fuel.

The general principles involved in all the various boiler designs are necessarily the same, although they have assumed a variety of different forms in the effort on the part of engineers to meet the varying conditions under which boilers have to be operated.

For this reason, it has become necessary to classify them by the marked peculiarities of construction which some of the more common makes possess, and we will, therefore, take up their discussion along the natural line of their development, and under the following heads: (1) Plain Cylindrical Boilers; (2) Flue-Boilers; (3) Tubular Boilers; (4) Water-Tube Boilers.

PLAIN CYLINDRICAL BOILERS.

2011. A plain cylindrical boiler is simply a long hollow cylinder made of wrought-iron or steel plates riveted together, after having been bent into the required shape. It is usually fitted with flat cast-iron heads, as shown in Figs. 649 and 650, although in some cases the heads are made hemispherical or "egg" ended, since this form offers the greatest possible resistance to bursting.

When such a boiler is in operation, the iron cylinder or shell, should be kept about two-thirds full of water, and that this may be done, a feed-water pipe *N*, leading into the boiler below the water-line *V*, Figs. 649 and 651, must be provided.

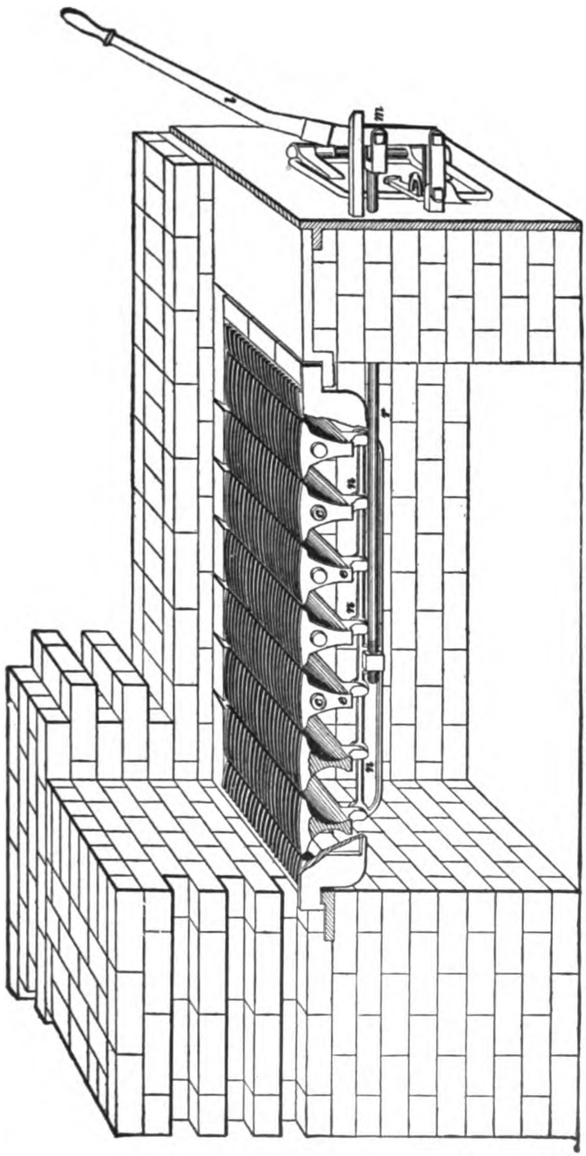


FIG. 654.

Fig. 650, closed with a manhole plate, yoke, and bolt, as shown, makes it possible for the fireman to remove the sediment and coating which from time to time are deposited in the shell by the evaporating water. Doors opening into the flues, etc., through the brickwork below the boiler also facilitate this cleaning process.

2017. Various means are employed for "setting" or supporting boilers in position. Care must be taken to so arrange the supports that the boiler-shell will be free to expand and contract with the changes of temperature.

In Figs. 649 to 651, the boiler is hung from wrought-iron channel-beams *I*, which rest upon the enclosing masonry work, and, whenever the plates expand or contract, the boiler swings a little on the hooks, one way or the other.

To add rigidity to the brick walls, buckstaves *L*, *L* are provided, which are bolted or keyed together above and below the boiler by long rods.

2018. In these boilers, as well as in all others, the furnace gases, when in their highly heated state, should be kept from coming in contact with those metal parts of the boiler which lie above the water-line *V*, since they tend, by overheating the metal, to cause a blistering of the plates and a burning off of the rivet-heads, that in time would produce serious leaks, if not an explosion. To prevent this, the masonry is made to abut against the boiler-shell just below the water-line, as seen in Fig. 651, and is frequently arched completely over the shell as well, for the purpose of diminishing the heat radiation from the metal parts of the boiler. All the masonry with which the flame does not come in contact is generally made of ordinary red brick or stone, while that with which the flame does come in contact is made of firebrick.

2019. The draft or rapidity with which the air flows through the grate of a boiler, for the purpose of supplying the fuel with a sufficient quantity of oxygen to insure its complete combustion, is usually produced by the chimney or smokestack, although it is frequently increased and made more efficient by connecting a blower with the ash-pit *D*.

There are a great many different kinds of these blowers, but the simplest and the one best adapted for boiler work is that represented in Figs. 649 to 651, at *X*. It consists simply of a long metal cylinder into which a jet of steam is led from the boiler by a ¾-inch pipe.

The steam, as it rushes through the pipe *Y* into the blower with great velocity, draws the air along with it, and the cylinder, by giving the blast the proper direction, causes it to impinge on the grate-bars *E*; thus a rapid and complete combustion of the coal is produced.

2020. Plain cylindrical boilers are little used at the present day, except in mining districts and other localities where fuel is very cheap, for they have so small a water-heating area, in proportion to the amount of water they contain, and the volume of gas given off from their furnaces, that they are very wasteful of heat energy. They are made from 28 to 50 inches in diameter, and from 20 to 60, and even 100, feet in length. This great length is given to increase the water-heating area.

FLUE-BOILERS.

2021. The flue-boiler represents a type in which an increased water-heating area is obtained by the introduction of one or two large flue-pipes within the boiler-shell, below the water-line. In Figs. 655 to 657 is shown an *externally fired flue-boiler*, or one in which the heated gases, after passing from the furnace, over the bridge-walls, and along in contact with the lower surface of the boiler till the space *H* is reached, are made to return through one or two large flues *A*, *A*, Fig. 657, fitted within the cylinder below the water-line.

From these flues the gases enter the smokebox *B*, and flow from there directly into the smokestack *C*. The arrangement of the masonry and the "setting" of the boiler-shell, in this instance, follows the construction of Figs. 649 to 651 so closely that no further explanation need be

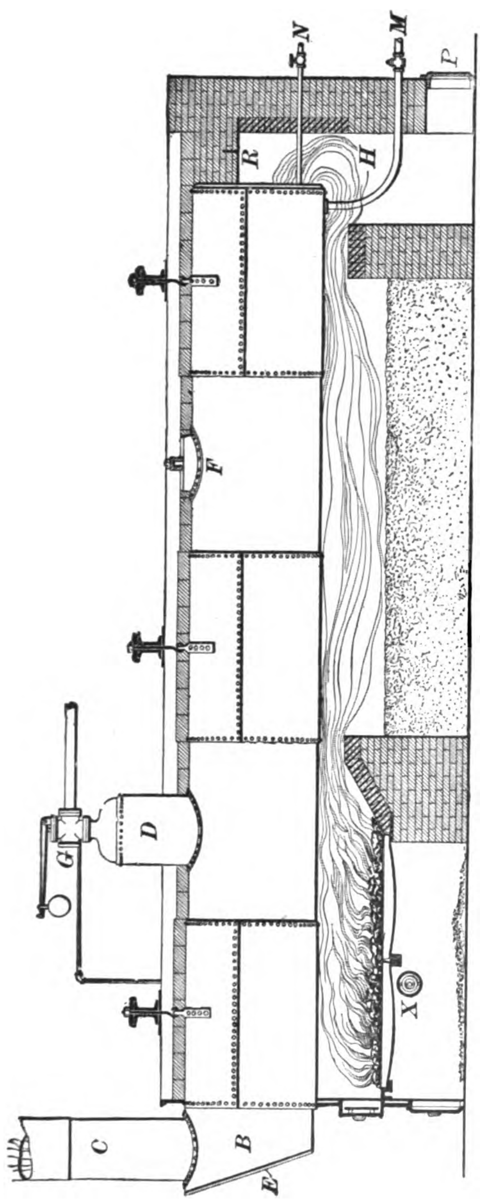


FIG. 655.

given, other than to call attention to the feed-pipe at *N*, the blow-off pipe at *M*, the steam-gauge at *K*, the gauge-cocks on the column *L*, and the steam-dome placed above the boiler at *D*. The steam-gauge and the gauge-cocks communicate with the boiler through the pipes *s* and *t*, the former passing into the steam-space and the latter into the water.

2022. There is generally a steam-dome on every boiler, which serves as a chamber in which the steam collects and is dried or relieved of a portion of its entrained water before passing to the engine. The hole in the shell of the boiler, over which the steam-dome is riveted, flat top of the fire-box is strengthened by a series of parallel girders *P*, *P*. As an additional security, the girders are sometimes attached to the shell by the "sling-stays" *R*, *R*.

The gases of combustion pass directly from the furnace through the tubes *T*, *T*, to the smokebox *B*, and out of the stack *C*. In railway locomotives, a strong draft is obtained by allowing the exhaust steam to discharge through the smokestack. The escaping steam carries along the air and the escaping gases in the smokebox *B*, thereby drawing a new supply of gases through the tubes *T*, *T*, and a supply of air through the grate.

The tubes of the locomotive boiler are about 12 feet long, two inches in diameter, and made of iron or steel. The tubes of stationary and portable boilers of this type are generally of larger diameter, as there is less demand for great quantities of steam. The locomotive type of boiler is **self-contained**; that is, it requires no brickwork for flues or for setting.

2025. The Return-Tubular Boiler.—This type of boiler is a development of the flue-boiler, the two large flues of the latter being replaced by a large number of small

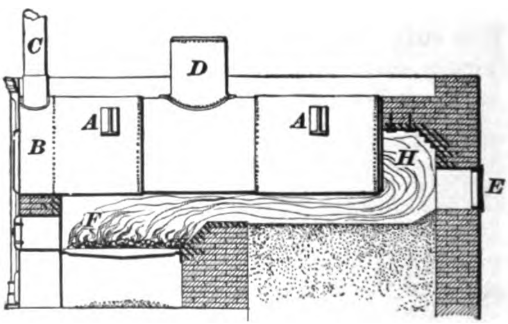


FIG. 660.

tubes. The object of introducing the numerous tubes is to increase the heating surface of the boiler.

A side view of a tubular boiler is shown in Fig. 660; a cross-section through the tubes is shown in Fig. 661. The tubes extend the whole length of the shell; the ends are beaded into holes in the heads of the boiler. The front end of the shell projects beyond the head, forming the smokebox *B*, into which opens the stack *C*.

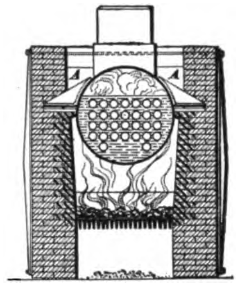


FIG. 661.

The shell is suspended on the side walls by the brackets *A*, *A*, which are riveted to the shell. The boiler is usually provided with a dome *D*, though this is sometimes left off. The walls are built and supported by buckstaves in practically the same manner as those previously described. Since this type of boiler is generally short, one bridge only is used. Firebrick is used for all parts of the wall exposed to the fire or heated gases. The fittings are not shown in the figure. The safety-valve would be placed on top of the dome, and the pressure-gauge and gauge-cocks would be placed on the front. The manhole is either in one of the heads or on top of the shell. The feed-pipe may enter the front head or the top, while the blow-off pipe is placed at the bottom of the shell, at the rear end. Access is given to the rear end of the boiler through the door *E*.

As usual, the furnace *F* is placed under the front end of the boiler. The gases pass over the bridge, along under the boiler into the chamber *H*, then back through the tubes to the smokebox *B*, and out of the stack *C*.

The return-tubular boiler is probably more used in the United States than any other. The details of its construction and setting will be shown later.

2026. The Vertical Boiler.—This type is essentially a modification of the locomotive type placed on end. A common form of vertical boiler is shown in Fig. 662. It consists of a vertical cylindrical shell, in the lower end of which is placed a fire-box *F*. The lower rim of the fire-box and the lower end of the shell are separated by a wrought-iron ring *k*, to which both are riveted, the rivets going through both plates and ring. The shell and fire-box are also stayed together by the staybolts *a*, *a*. The space between the two is filled with water, so that the fire-box is nearly surrounded by it. The boiler-shell, and likewise the grate *E*, rest upon a cast-iron base *D* which forms the ash-pit. A series of vertical tubes *t*, *t* extend from the top sheet of the fire-box to the upper head of the shell. The tubes serve as stay-rods and strengthen the flat surfaces which they connect. The upper ends of the tubes open directly into the chimney or smokestack *K*. The gases from the furnace thus pass directly through the tubes and out of the stack.

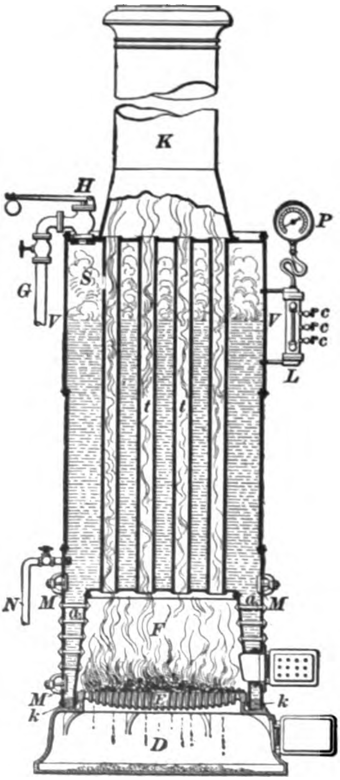


FIG. 662.

The safety-valve is shown at *H*, with the main steam-pipe *G* leading from it. The pressure-gauge *P* and gauge-cocks *c*, *c*, *c* are attached to a column *L*, which communicates in the usual manner with the interior of the shell. The construction of this type of boiler does not generally permit the use of manholes, but handholes *M*, *M* are placed in convenient positions for cleaning out mud and sediment.

The boiler is fed through the feed-pipe *N*, which is connected to a pump or injector.

When the tubes extend through to the upper head of the boiler, as shown in Fig. 662, their upper ends pass through the steam-space *S* above the water-line *V V*. This is considered to be a bad feature, since the tubes are liable to become overheated and to collapse, when the boiler is subject to rapid firing.

In the form of vertical boiler shown in Fig. 663, this danger is avoided. A chamber or smokebox *I* extends down from the upper head of the shell so that its bottom plate is always below the water-line. The upper ends of the tubes *t*, *t* are expanded into the lower plate of this chamber, and, therefore, the tubes are always surrounded by water from end to end. A vertical boiler constructed in this manner is said to have a *submerged head.* Aside from the submerged head, the construction of the boiler of Fig. 663 is similar to that of Fig. 662.

Vertical boilers are generally wasteful of fuel; they are, however, self-contained, require but little floor space, and are easy to construct and repair. For these reasons, the vertical type of boiler is very popular with a large class of steam-users.

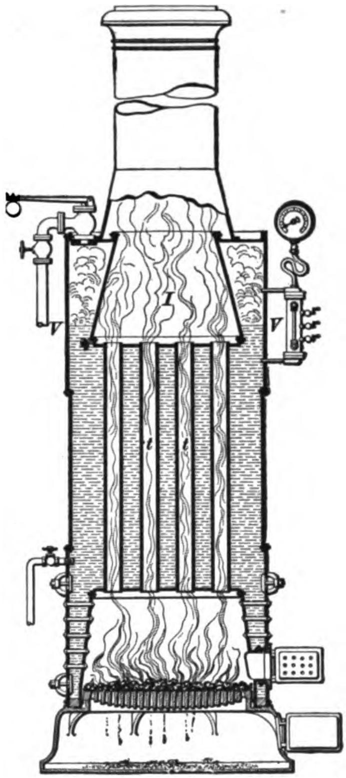


FIG. 663.

WATER-TUBE BOILERS.

2027. The **Babcock and Wilcox water-tube boiler** is shown in Fig. 664. It consists essentially of a main horizontal drum *B* and of a series of inclined tubes *T*, *T*. (Only a single vertical row of tubes is shown by the figure, but it will be understood that each nest of tubes is composed of several vertical rows.) There are usually 7 or 8 of these vertical rows to each horizontal drum. The front ends of the tubes of a vertical row are all expanded into a hollow iron tubes are expanded into the large wrought-iron water-legs *B*, *B*. These legs are flanged and riveted to the shell. The shell is cut out for about ¼ the circumference to receive the water-legs, the opening being from 60 to 90 per cent. of the cross-sectional area of the tubes. The drum-heads are of a hemispherical form, and, therefore, do not need bracing.

The water-legs form the natural support of the boiler.

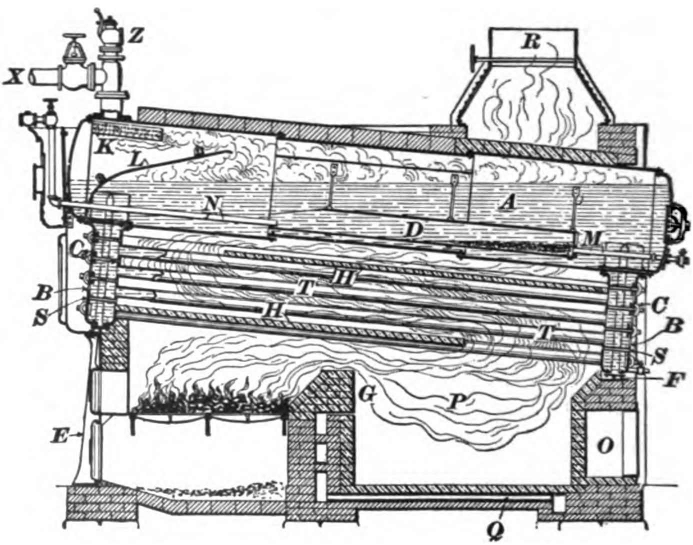


FIG. 665.

The front water-leg is placed on a pair of cast-iron columns *E* which form part of the front of the boiler. The rear water-leg rests on rollers (shown at *F*) which may move freely on a cast-iron plate bedded in the rear wall. The rollers allow the boiler to expand when heated.

The boiler is enclosed by a brickwork setting in the usual manner. The bridge *G* is made largely of firebrick. It is made hollow, and has openings in the rear to allow air to pass into the chamber *P* and mix with the furnace gases. The air is drawn from the outside through the channel *Q* in the side wall. The air is, of course, heated in passing through the bridge. In the rear wall is the arched opening *O*, which is closed by a door, and further protected by a thin wall of firebrick. When it is necessary to enter the chamber *P*, the wall may be removed and afterwards replaced.

The feed-water is brought in through the feed-pipe *N*, which passes through the front head. As the water enters, it flows into the mud-drum *D*, which is suspended in the main drum below the water-line, and is thus completely submerged in the hottest water in the boiler. This high temperature is useful in precipitating the impurities contained in the feed-water. These impurities settle in the mud-drum *D*, and may then be blown out through the blow-out pipe *M*.

Layers of firebrick *H*, *H* are laid at intervals along the rows of tubes, which act as baffle-plates, and force the furnace gases to pass back and forth through the tubes. The gases finally escape through the chimney *R* placed above the rear end of the boiler. To protect the steam-spaces of the drum from the action of the hot gases, the drum in the vicinity of the chimney is protected by firebrick, as shown in the figure.

The steam is collected and freed from water by the perforated dry-pipe *K*. The main steam-pipe with its stop-valve is shown at *X*, the safety-valve at *Z*. In order to prevent a combined spray of mixed water and steam from spurting up from the front header and entering the dry-pipe, a deflecting plate *L* is placed in the front end of the drum.

A manhole *Y* is placed in the rear head of the drum. The flat sides of the water-legs, which are made hollow to give access to the outside of the tubes, are stayed together by the staybolts *S*, *S*. In front of each tube, a handhole *C* is placed to give access to the interior of the tubes.

Where a battery of several of these boilers is used, an additional steam-drum is placed above and at right angles to the drums *A*, *A*.

2029. The **Stirling boiler,** shown in Fig. 666, is a departure from the regular type of water-tube boilers. It consists of a lower drum *A*, connected with three upper drums *B*, *B*, *B* by three sets of nearly vertical tubes. These upper drums are in communication through the curved tubes *C*, *C*, *C*. The curved forms of the different sets of tubes allow the different parts of the boiler to expand and contract freely without strain.

The boiler is enclosed in a brickwork setting, as shown.

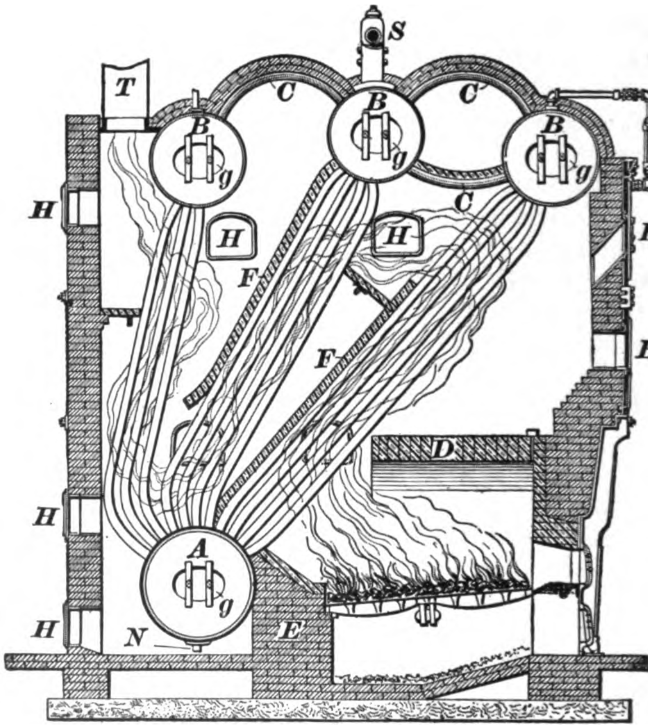


FIG. 666.

The setting is built with various holes *H*, *H*, so that the interior may be inspected or repaired.

The boiler is suspended from a framework of wrought-iron girders, not shown in the figure.

The bridge *E* is lined with firebrick, and is built in contact with the lower drum *A* and the front nest of vertical tubes. An arch *D* is built above the furnace, and this, in connection with the bafflers *F*, *F*, directs the course of the heated gases, causing them to pass up and down through the tubes. The arch and bafflers are made of firebrick.

The cold feed-water enters the rear upper drum and descends through the rear nest of tubes to the drum *A*, which acts as a mud-drum, and collects the sediment brought in by the water. A blow-off pipe *N* permits the removal of the sediment. The steam collects in the upper drums *B*, *B*. To the middle drum is attached the steam-pipe and safety-valve *S*.

The chimney *T* is located behind the rear upper drum. Therefore, the cold feed-water enters the coolest part of the boiler, and the circulation of the water is directly opposite to that of the escaping hot gases.

The water-column *L* with its fittings is placed in communication with the front upper drum. All the drums are provided with large manholes *g*.

The boiler is made with a cast-iron front.

2030. The following advantages are claimed for the Stirling boiler:

(1) The vertical position of the tubes prevents the collection of sediment, and at the same time encourages the rapid rise and separation of the steam as soon as it is formed. (2) The boiler is very simple and easy to construct; there are no flat surfaces to be stayed, and there is little or no machine work required in its manufacture. (3) It is very accessible for cleaning or repairs; any part of the boiler may be inspected by removing the four manhole plates *g*.

The various water-tube boilers just described are coming into extensive use. The most important points in their favor are their safety from disastrous explosion and their economy in the use of fuel. An objection sometimes urged against water-tube boilers is that they require more attention; since they usually have much less cubic capacity than cylindrical boilers of the same power, the water-level must be closely watched.

STRENGTH OF BOILERS.

2031. Steam-boilers can be designed and constructed to safely generate and operate under almost any desired steam pressure, however great it may be. The common practice among engineers, however, is rarely, if ever, to go above 250 pounds per square inch, and in the majority of plants throughout the country the steam pressure does not exceed 60 pounds per square inch.

2032. In approximately determining the safe working pressure under which any well-designed boiler may be operated, it is only necessary to find the diameter of the largest cylindrical shell used in its construction, and the thickness of the plate of which the shell is made. Then the safe working pressure may be found by the following rule:

Rule.—*Multiply the thickness of the plate in inches by the constant given below, and divide the product by the diameter of the shell in inches; the quotient will be the allowable gauge pressure.*

Let p = safe working pressure;
t = thickness of plate in inches;
d = diameter of shell in inches;
c = constant.

Then, $$p = \frac{c\,t}{d}. \qquad \textbf{(141.)}$$

The following constants are to be used in formula **141**:

Wrought-iron plate, single-riveted joint	10,224
Wrought-iron plate, double-riveted joint	13,152
Steel plate, single-riveted joint	16,608
Steel plate, double-riveted joint	20,688

EXAMPLE.—If a return-tubular boiler is made of $\frac{5}{16}$ of an inch thick wrought-iron boiler plate, double riveted, and is 5 feet in diameter, what is the greatest steam pressure under which such a boiler can be safely operated?

SOLUTION.—Applying formula **141**,

$$p = \frac{13,152 \times \frac{5}{16}}{60} = 68.5 \text{ pounds per square inch, gauge. Ans.}$$

68.5 + 14.7 = 83.2 pounds per square inch above a vacuum.

HORSEPOWER OF BOILERS.

2033. The **horsepower** of a boiler is a measure of its capacity for generating steam. Boiler-makers usually rate the horsepower of their boilers as a certain fraction of the heating surface; but this is a very indefinite method, for with the same heating surface, different boilers of the same type may, under different circumstances, generate different quantities of steam.

In order to have an accurate standard of boiler-power, the American Society of Mechanical Engineers has adopted as a standard horsepower *an evaporation of 30 pounds of water per hour from a feed-water temperature of 100° F. into steam at 70 pounds gauge pressure*, which is considered equivalent to 34.5 units of evaporation; that is, to 34.5 pounds of water evaporated from a feed-water temperature of 212° F. into steam at the same temperature.

EXAMPLE.—A boiler evaporates per hour 1,980 pounds of water from a feed temperature of 100° into steam at 70 pounds gauge pressure. What is the horsepower of the boiler?

SOLUTION.—Since, under the given conditions, an evaporation of 30 pounds is equivalent to one horsepower, the number of horsepower is $1{,}980 \div 30 = 66$. Ans.

2034. In the various types of boilers there is a nearly constant ratio between the water-heating surface and the horsepower, and also between the heating surface and the grate area. These ratios are given in the following table:

TABLE 43.

RATIO OF HEATING SURFACE TO HORSEPOWER AND OF HEATING SURFACE TO GRATE AREA.

Type of Boiler.	$\text{Ratio} = \frac{\text{Heating Surface}}{\text{Horsepower}}$	$\text{Ratio} = \frac{\text{Heating Surface}}{\text{Grate Area}}$
Plain Cylindrical	6 to 10	12 to 15
Flue	8 to 12	20 to 25
Return-Tubular.	14 to 18	25 to 35
Vertical	15 to 20	25 to 30
Water-Tube	10 to 12	35 to 40
Locomotive	1 to 2	50 to 100

height. The area of a chimney is usually made from one-seventh to one-tenth as large as the area of the furnace-grates, or of about the same cross-section as the cross-sectional area of the flues or tubes; we have, therefore, a comparatively simple method of determining one of the required dimensions of a chimney, and, when this is known, it becomes an easy matter to determine the height of the chimney when the horsepower of the boiler has been ascertained.

The horsepower of a boiler being given and the necessary chimney area having been determined, the following rule gives the required height that the chimney must be to produce the necessary draft :

Rule.—*From 3.33 times the area of the chimney in square feet, subtract twice the square root of the area of the chimney in square feet, and divide the given horsepower by the remainder. The square of the quotient will be the height of the chimney in feet.*

Let A = area of chimney;
H = horsepower of boiler;
h = height of chimney.

Then, $$h = \left(\frac{H}{3.33\,A - 2\sqrt{A}}\right)^2. \qquad \textbf{(142.)}$$

EXAMPLE.—What must be the height of a chimney which is to have a cross-sectional area of 7 square feet, and to supply the draft for a 141 horsepower boiler ?

SOLUTION.—Using formula **142**,

$$h = \left(\frac{141}{3.33 \times 7 - 2\sqrt{7}}\right)^2 = \left(\frac{141}{3.33 \times 7 - (2 \times 2.65)}\right)^2 = 61.8 \text{ feet. Ans.}$$

STEAM-ENGINES.

THE PLAIN SLIDE-VALVE ENGINE.

GENERAL DESCRIPTION.

2037. The **plain slide-valve engine** is the most simple of all of the many forms of steam-engines now in use. In its construction and operation, however, all of the fundamental principles of this class of machinery are involved.

2038. In Fig. 667 such an engine is shown, and in Fig. 668 is shown an enlarged section of a steam-cylinder. Referring to these figures, *H* is the head end and *C* the crank end of the steam-cylinder; *B* and *B'* are the steam-ports; *D* is the steam-chest; *E* is the exhaust-port; *N* and *N'* are the cylinder-heads; *S* is the steam supply-pipe; *O* is the exhaust-pipe, and connects with the exhaust-port *E*; *G* is one of the two guide-bars (the other, which is not designated, is on the opposite side of the cross-head *2*); *R* and *R'* are the shaft-bearings, and *T* is the bed or frame of the engine. The above are all stationary parts of the engine, or parts which do not change their relative positions when the engine is in motion. *P* is the piston; *1* is the piston-rod; *2* is the cross-head; *3* is the cross-head pin; *4* is the connecting-rod; *5* is the crank; *6* is the crank-pin; *7* is the crank-shaft; *8* is the fly-wheel; *9* is the eccentric; *10* is the eccentric-strap; *11* is the eccentric-rod; *12* is the rocker; *13* is the valve-rod, or stem, and *V* is the slide-valve. These are all movable parts of the engine, or parts which change their relative positions when the engine is in motion.

2039. The stroke of the engine is equal to the throw of the crank, or to the diameter of the circle described by the center of the crank-pin *6*. It is also equal to the cross-head or piston travel, or the distance through which the cross-head or piston moves, and it determines the working length *W* of the cylinder, as shown in Fig. 668. The bore of the cylinder is *M*, Fig. 668. The counter-bores *F* and *F'* are enlargements, into which the piston projects at the end of each stroke. They prevent the formation of shoulders at the ends of the cylinder by insuring an equal wear of the cylinder over its entire working length. Such shoulders would cause a pounding of the piston when the length of the

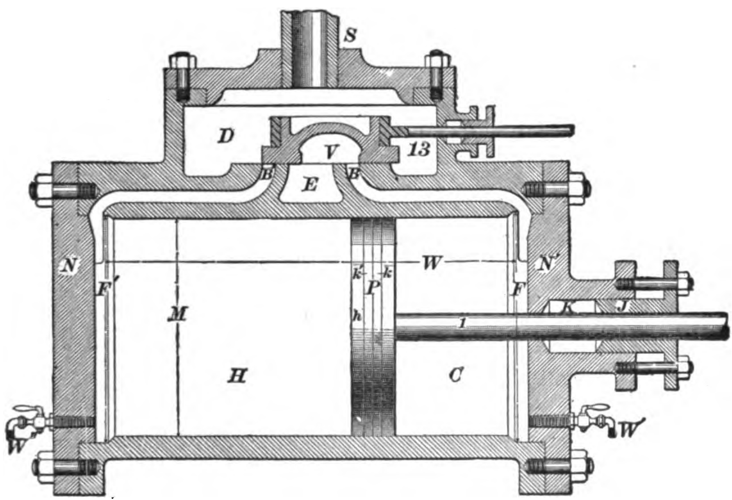


Fig. 668.

connecting-rod is increased by the taking up of the wear of its joints. The clearance at one end of the cylinder is the volume that remains when the piston has completed its stroke—it includes the steam-port. It is diminished at the crank end by the volume of that portion of the piston-rod remaining within the cylinder. The volume of the cylinder is equal to the volume of the clearance at one end plus the volume swept through during one stroke of the piston. It is less at the crank end by an amount equal to the volume of that portion of the piston-rod remaining in the cylinder.

Drain-valves W' and W'' are fitted in each end of the cylinder through which any condensed steam may be discharged.

The piston is given a loose fit in the cylinder, and has split rings *k* and *k'* inserted, which spring out so as to press against the wall of the cylinder, and prevent leakage of steam between the wall of the cylinder and piston. Pistons are usually supplied with a follower-plate *h*, which is bolted to the head end of the piston *P*, in order to hold these split rings *k* and *k'* in place. The piston-rod *1* is a perfectly round, smooth bar, rigidly connected to both the piston *P* and the cross-head *2*.

K is a stuffing-box in which packing is placed, and is fitted with a gland *J*, which, when bolted down, compresses the packing around the piston-rod *1*, and makes a steam-tight joint. This packing is usually made in the form of split rings, which are so placed that the split of the first ring is covered by the solid part of the next ring. When repacking, care should be taken not to cause unnecessary friction by too much pressure from the gland. The cross-head *2* is given an easy sliding fit between the guide-bars, which are in line with the path of the piston-rod, and combine with the cross-head to relieve the piston-rod of all bending strains.

2040. The connecting-rod *4* forms the connecting-link between the cross-head and crank *5*. The joint between the cross-head *2* and connecting-rod *4* is made by the cross-head pin *3*, and that between the connecting-rod and crank by the crank-pin *6*. Connecting-rods are usually made from 2 to 3 times the length of the stroke, or from 4 to 6 times the length of the crank, or from 4 to 6 "cranks" in length, as it is called.

The crank-shaft *7* forms a rigid connection between the crank *5*, the eccentric *9*, and the fly-wheel *8*. The power developed in the engine is, therefore, transmitted through the shaft. When the engine is running, all the energy which has been expended in giving the fly-wheel its speed is stored up in the fly-wheel. This energy, from the law of pressure. Suppose, further, that there is a coiled spring on top of the piston; that a piston-rod passes through the center of the spring, and that a pencil is attached to the end of the piston-rod. If a pressure of 10 pounds is required to compress the spring 1 inch, it is evident that for every 10 pounds pressure in the cylinder, the pencil will move upwards 1 inch, and, if it touched a sheet of paper, would mark a line on that paper. It will now be presumed that an arrangement like that just described is attached to the steam-engine piston, and that the pencil touches a sheet of paper, which is held stationary. Then, when the steam-piston moves ahead, the pencil will make straight lines at heights corresponding to the steam-pressure on the under sides of the little pistons, except when the pressure of the steam in cylinder varies, in which case the pencil will move up or down, according as the pressure increases or diminishes.

Having made these suppositions clear, let $Q\ X$, Figs. 670 to 672, represent the line which the pencil would trace if there were a perfect vacuum in the cylinder; i. e., $Q\ X$ is the line of zero pressure, or the **vacuum line**; also let $A\ B$ represent the **atmospheric line,** or the line which the pencil would trace if the pressure in the cylinder was just equal to that of the atmosphere, and $Q\ Y$ the line of no volume. Then, the point Q represents no volume and no pressure. Finally, let $1\ D$ represent the volume of the clearance; that is, the space between the piston and cylinder-head when the piston is at the end of its stroke.

2044. Consider Fig. 670 (*a*). The piston is represented as just beginning the forward stroke, and the valve as just commencing to open the left steam-port, both moving in the same direction, as shown by the arrows. If the valve had no outside lap (see Art. **2047**), the position of the eccentric center would be at e, but on account of the lap, the valve has moved ahead of its central position in order to bring its edge to the edge of the port. To accomplish this, the eccentric center has been moved from e to b, $O\ b$ being the position of the eccentric radius. The angle $b\ O\ e$, Assume that the piston and valve have moved a very small distance, just sufficient to admit steam to fill the clearance-space on the left of the piston, so that the steam acts on the piston at full boiler-pressure. If the length of the line *A 1* represents the boiler-pressure (gauge), the pencil which registers the pressure on the left side of the piston will be at *1*. The steam on the right side of the piston is flowing (*exhausting*) into the atmosphere through the exhaust-port, as shown by the arrow. As the size of the exhaust-port is limited by practical considerations, the exhaust is not perfectly free, and there is a slight pressure on the exhaust side of the piston, in addition to the atmospheric pressure. This is termed **back-pressure.** Therefore, in the diagram *N*, let *1* be the position of the second pencil; then, *1 B* is the back-pressure.

In Fig. 670 (*b*) the piston has advanced far enough to enable the valve to reach the end of its stroke and open the port its full width. The crank and eccentric have moved to the positions *O a* and *O b*. The eccentric radius is horizontal, and any further movement of the crank will cause the eccentric to travel in the lower half of its circle and make the valve move back. In the diagrams *M* and *N*, the pencil has traced the lines *1–3*.

Fig. 671 (*a*) marks one of the most important points of the stroke. Here the valve has closed the steam-port, i. e., *cut off* the steam, and from here to the end of the stroke, the steam in the cylinder expands. This point of the stroke is called the **point of cut-off.**

The exhaust-port is now partially closed. The crank and eccentric have moved to the positions indicated. During this movement, the pencils have traced the lines *3–5*.

Fig. 671 (*b*) shows another very important valve position. Here the inside edge of the valve closes the exhaust-port, and, from now on to the end of the stroke, the steam in front of the piston is compressed. This point of the stroke is called the **point of compression.** In the diagrams *M* and *N*, the lines *5–6* are traced by the pencils. The line *5–6* on the diagram *M* is an expansion line, the pressure falling and a half times its volume at the point of cut-off, or its volume is increased by the expansion in the cylinder an amount equal to one-half of what it was at cut-off.

In practice, the point of cut-off can be obtained directly from the engine. Measure the distance between the dead-center points as marked on the guide-bars; this will be the length of the stroke. Take off the steam-chest cover, and with the piston at the head end of the cylinder, slowly rotate the engine forwards until the head edge of the slide-valve coincides with the head edge of the steam-port. Then measure the distance between the head dead-center guide-bar mark and the mark on the cross-head; divide this latter quantity by the one first taken, and the result will be the cut-off required, in a fraction of the stroke. Plain slide-valves usually cut off between ½ and full stroke.

CORLISS VALVE-GEAR.

2053. As has been stated before, the plain slide-valve involves all the principles made use of in any of the more complicated forms of valve-gear at present in use. The *Corliss valve-gear* is, however, being so extensively employed in different kinds of machinery, that a short description of its working parts and principles is here given.

In Fig. 675 is shown a side elevation of this valve-gear, and in Fig. 676 a section through the cylinder and valves.

It has four separate and distinct valves. Two of these, *v* and *v'*, Fig. 676, connect directly with the steam-chest *d* and steam-pipe *s*, and are called steam-valves. They are rigidly connected with the cranks *N* and *N'*, Fig. 675, *N'* being removed in order to show more clearly the disengaging link *I'*. The other two valves, *r* and *r'*, Fig. 676, connect directly with the exhaust-chest *l* and the exhaust-pipe *o*, and are called exhaust-valves; they are rigidly connected with the cranks *M* and *M'*, Fig. 675. All the valves are cylindrical in form, and extend across the cylinder above and below, respectively.

A, Fig. 675, is a disk or wrist-plate, which is made to rock of which the valve-cranks *N* and *N'* were raised. The movements of the valves open and close the steam and exhaust ports of the cylinder at the proper intervals. The pins of the valve-stems are so located on the wrist-plate that the steam-valves *V* and *V'* have their quickest movement while the exhaust-valves *R* and *R'* have their slowest movement, and the exhaust-valves have their quickest movement while the steam-valves have their slowest movement. As a consequence of this arrangement, the steam and exhaust valves have entirely independent movements, and the inlet-ports may be suddenly opened full width by the quick movement of the steam-valves, while the exhaust-valves are practically motionless. The advantage of this valve-gear is that it permits an earlier cut-off, with a greater range and a more perfect steam distribution, than is attained with the plain slide-valve.

Engines fitted with the Corliss valve-gear can not run at much more than 90 revolutions per minute.

INDICATORS AND INDICATOR-CARDS.

DESCRIPTION OF THE INDICATOR.

2054. In Fig. 681 and 682 are given diagrams (*1–2–3–4–5–6*) in which vertical distances represent pounds pressure per square inch, and horizontal distances the position of the piston in its stroke. Such a diagram is called an **indicator-diagram.** Indicator-diagrams are obtained by making use of an instrument called an **indicator,** Fig. 677, which is fitted to the steam-engine cylinder, as shown in Fig. 679. Holes are drilled into the clearance-spaces of the steam-cylinder (see *H* and *C*, Fig. 679), and connected with a pipe *O*, having a three-way cock *Q* in the middle. The indicator is securely fitted to the arm *F* of the three-way cock by inserting the projection *s* (see Fig. 678) in the end of the arm, and tightening up by the nut *r*.

It is the office of the three-way cock to check the passage of the steam when the indicator is not in use, but it can be pounds pressure per square inch on the piston *g* to compress it sufficiently to move the pencil-lead at *p* vertically one inch on the drum *f*, therefore the pencil-lead at *p* will mark on the drum *f* vertical lines proportional to the pressure behind the piston, during the various points of its stroke. If we now close the passage *H Q* to steam and open the passage *C Q F*, by turning the cock at *Q*, the pencil will in this case

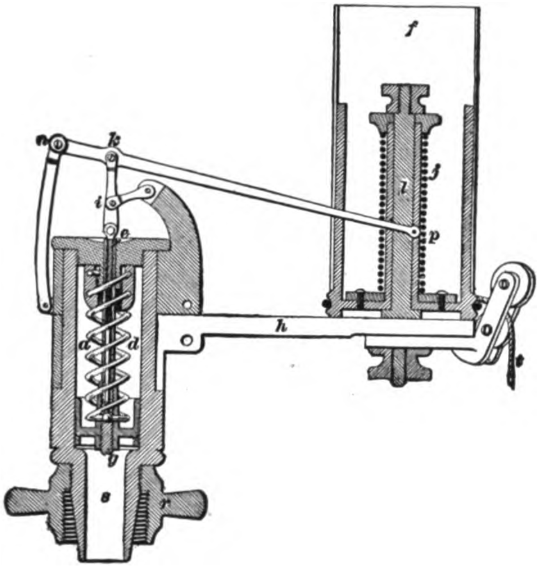


FIG. 678.

have a vertical movement proportional to the steam-pressure behind the piston in the crank end of the steam-cylinder.

2055. The **scale** of an indicator-spring is the number of pounds pressure per square inch on the indicator-piston necessary to give the pencil-lead a movement through a vertical distance of one inch, and it should not be less than ½ the boiler-pressure under which the engine is operated.

The spindle *l*, Fig. 678, is firmly fixed to the bar *h*, and is also connected to the drum *f* by means of the spring *j*. If, now, the cord *t*, which is wound on the drum, is pulled, the drum *f* will rotate against the action of the spring, but it

EXAMPLE.—The area of the diagram is 4.2 sq. in., and the length is 3.5 in.; a 40 spring being used, find the M. E. P.

SOLUTION.— $\frac{4.2}{3.5} \times 40 = 48$ lb. per sq. in., M. E. P. Ans.

2063. Where a planimeter is not available, the following method of finding the M. E. P. is fairly rapid and accurate:

Draw tangents to each end of the diagram perpendicular to the atmospheric line. Divide the horizontal distance between the tangents into 10 or more equal parts. (10 or 20 parts are the most convenient, but any other number may be used.) Indicate by a dot on the diagram the center of each division, and draw lines through these dots, parallel to the tangents, from the upper line to the lower line of the diagram. On a strip of paper mark off successively the lengths of these lines, the total length thus representing the sum of all the lines. Divide this total length by the number of lines used, and multiply the quotient by the scale of the spring. The result will be the M. E. P.

EXAMPLE.—The projection of the diagram shown in Fig. 682 upon the atmospheric line is *A Z*; that is, lines perpendicular to this line, drawn through the extreme ends *1* and *4* of the diagram, cut it (the atmospheric line) in *A* and *Z*. *A Z* is divided, in this case, into 14 equal spaces. The length of each of the perpendicular lines drawn through the diagram opposite the centers of these spaces is marked on the line itself, and the sum of these lengths is 18.11 inches. The scale of the spring used in obtaining the diagram was 40 pounds; therefore, $\frac{18.11}{14} \times 40 = 51.74$ pounds per square inch = the M. E. P. of the bottom-end diagram.

EXAMPLE.—The projection of the diagram, Fig. 681, upon the atmospheric line is the distance *A Z*, and it is divided, in this case, into 14 equal spaces. The length of each of the perpendicular lines drawn through the diagram opposite the centers of these spaces is marked on the line itself, and the sum of these lengths is 17.78 inches. The scale of the spring is 40 pounds; therefore, $\frac{17.78}{14} \times 40 = 50.8$ pounds per square inch = the M. E. P. of the top-end diagram.

Therefore, the M. E. P. in the cylinder during a complete revolution of the crank is $\frac{51.74 + 50.8}{2} = 51.27$ pounds per square inch.

2064. The reason for dividing the diagram into 10 parts instead of some other number is that it shortens the work of calculation. Thus, in the two examples just given, if the number of divisions had been 10 instead of 14, and the sum of the ordinates had been 12.94 inches, the mean ordinate would have been $\frac{12.94}{10} = 1.294$ inches, and the M. E. P., $1.294 \times 40 = 51.76$ lb. per sq. in. All that is necessary is to add the ordinates and shift the decimal point one place to the left to obtain the mean ordinate when the diagram is divided into 10 equal parts. This method saves the time required to divide by some inconvenient number, such as 14.

2065. In Figs. 681 and 682, the vertical line *a b* represents the boiler-pressure, and, therefore, the dotted line *b c* is the line that the indicator-pencil would trace if the full boiler-pressure were maintained until point of cut-off. The line *b c* is not drawn by the indicator as ordinarily used; it has been added for sake of illustration.

2066. We have now all the material required for finding the work done in the engine-cylinder expressed in horsepower units.

Work is the product of force into the distance through which it moves. In the case of the engine-cylinder, the total force is the M. E. P. per square inch multiplied by the area of the piston; and the distance moved through in one minute is the number of strokes per minute multiplied by the length of the stroke.

2067. **Rule.**—*To find the* **indicated horsepower** *developed by the engine, multiply together the M. E. P. per square inch, the area of the piston, the length of stroke, and the number of strokes per minute. This gives the work per minute in foot-pounds. Divide the product by 33,000; the result will be the indicated horsepower of the engine.*

Let I. H. P. = indicated horsepower of engine;
P = M. E. P. in pounds per square inch;
A = area of piston in square inches;
L = length of stroke in feet;
N = number of strokes per minute.

Then, the above rule may be expressed thus:

$$\text{I. H. P.} = \frac{P L A N}{33,000}. \qquad \textbf{(143.)}$$

2068. The number of strokes per minute is twice the number of revolutions per minute. For example, if an engine runs at a speed of 210 revolutions per minute, it makes 420 strokes per minute. A few types of engines, however, are single-acting; that is, the steam acts on only one side of the piston. Such are the Westinghouse, the Willans, and others. In this case, only one stroke per revolution does work, and, consequently, the number of strokes per minute to be used in the above rule is the same as the number of revolutions per minute. As most steam-engines are double-acting, no mention is generally made of this fact. When the dimensions of an engine are given, unless it is stated that the engine is single-acting, it may be assumed that a double-acting engine is meant and that work is done during each stroke.

EXAMPLE.—The diameter of the piston of an engine is 10 inches, and the length of stroke 15 inches. It makes 250 revolutions per minute, with a M. E. P. of 40 pounds per square inch. What is the horsepower?

SOLUTION.—As it is not stated whether the engine is single or double acting, assume that it is double-acting. Then, the number of strokes is $250 \times 2 = 500$ per minute. Applying formula **143**,

$$\text{I. H. P.} = \frac{P L A N}{33,000} = \frac{40 \times \frac{15}{12} \times (10^2 \times .7854) \times 500}{33,000} = 59.5 \text{ H. P.}$$

2069. Approximate Determination of M. E. P.—To approximately determine the M. E. P. of an engine, when the point of apparent cut-off is known and the boiler-pressure, or the pressure per square inch in the boiler from which the supply of steam is obtained, is given:

Rule.—*Add 14.7 to the gauge-pressure, and multiply the result by the number opposite the fraction indicating the point of cut-off in Table 44. Subtract 17 from the product and multiply by .9. The result is the M. E. P. for good, simple non-condensing engines.*

For example: indicator-diagrams, taken from an engine while running under full load, and having a piston speed of 498 feet per minute, show an *indicated horsepower* of 242.7. With the same piston speed, and running under no load, the indicator-diagrams show an *indicated horsepower* of 75.2. Then, $242.7 - 75.2 = 167.5$ = the *actual horsepower* of the engine.

2075. The **mechanical efficiency** of an engine is the ratio of the *actual horsepower* to the *indicated horsepower;* or it is the per cent. of the mechanical energy developed in the cylinder which is utilized in the doing of useful work.

2076. To find the efficiency of an engine, when the *indicated* and *actual horsepowers* are known:

Rule.—*Divide the actual horsepower by the indicated horsepower.*

Let N. H. P. = the net, or actual, horsepower;
I. H. P. = the indicated horsepower;
E_m = efficiency of engine.

Then, $$E_m = \frac{\text{N. H. P.}}{\text{I. H. P.}} \qquad \textbf{(146.)}$$

EXAMPLE.—The indicator-diagrams taken from an engine running under full load show the I. H. P. to be 238.5. The diagrams taken when the engine is running under no load show a horsepower of 39.7. (*a*) What is the net H. P. developed by the engine? (*b*) What is the efficiency of the engine?

SOLUTION.—(*a*) Net H. P. = I. H. P. − friction H. P. = $238.5 - 39.7 = 198.8$. Ans.

(*b*) By formula **146**, the efficiency is

$$\frac{\text{N. H. P.}}{\text{I. H. P.}} = \frac{198.8}{238.5} = 83.4\%. \text{ Ans.}$$

The mechanical efficiency of a good engine may be from 75 to 90 per cent.

The efficiency of steam-engines varies greatly; it is, however, usually taken at 66 per cent. in all approximate determinations. That is, ordinary practice shows that with the types of engine commonly used only about .66 or $\frac{2}{3}$ of the power developed in the cylinder is actually available.

have produced the same cards. The atmospheric line drawn by the indicator pencil would have been at *a z* at a scale distance of 12 pounds above the old atmospheric line *A Z*, or 6 pounds above the back pressure line *4–5*. In effect every point on the card would be lowered a scale distance of 12 pounds.

STEAM-ENGINE GOVERNORS.

2080. Steam-engine governors are mechanical devices which automatically regulate the steam-supply of an engine, so that when the load on the engine is increased or decreased, or when the steam-pressure under which it operates changes, the speed of the engine will remain constant. It must not, however, be thought that the duty of the governor is to adjust the working conditions of an engine to any sudden variation of steam-pressure or load that may occur during the time of a single stroke of the piston. It is the office of the fly-wheel to respond to these rapidly changing conditions, and by the resistance which it offers to any rapid change in its velocity, to gradually absorb this sudden force in increasing and decreasing the number of its revolutions per minute. When the engine is not supplied with a fly-wheel, there are other rotating parts, such as the drum of a hoisting-engine, which serves the same purpose. Any variation of the speed of the fly-wheel is, however, met by the action of the governor, which increases or decreases the steam-supply, and thereby restricts the velocity of the fly-wheel within certain limits. The principle that insures the action of all steam-engine governors is that of the equalization of two opposing forces, which will occur only when the engine is running at its proper speed. Any variation of the speed tends to give one of these forces an increase over the other, which is expended in moving some mechanism for the adjustment of the steam-supply.

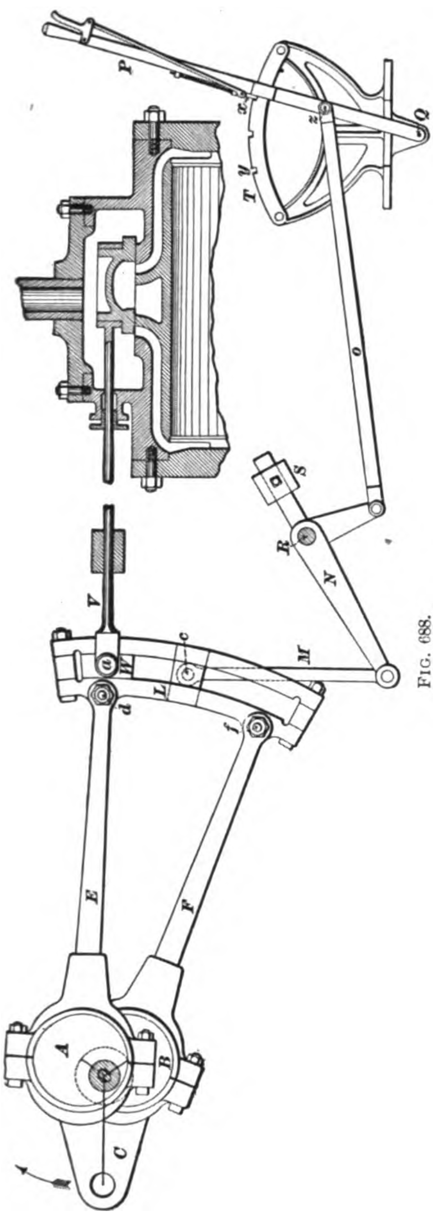


FIG. 688.

that the direction of rotation of the drum may be reversed at will. This introduces a new feature, namely, a **reversing-gear,** which must form a part of every engine of which the direction of motion is to be reversed. The most common form of reversing-gear is the Stephenson link-motion, which can be partly seen in Fig. 687, but is more clearly shown in Fig. 688; the lettering, however, applies alike to both figures.

2086. Let *O* be the center of rotation of the crank *C*, and suppose the arrow to represent the forward rotation of the engine. Then, *A* will be the forward eccentric and *B* the backward eccentric; *E* will be the forward eccentric-rod, and *F* the backward eccentric-rod.

The forward eccentric, for reasons already explained, must be slightly more than a right angle in advance *a* and *c*, in *a*'s new position. When *c* reaches *a*, there will be no travel of the valve, and for points between *c* and *f* the valve-travel will again increase directly as the distance between *a* and *c* increases.

This means that, as in the case of an automatic governor, we can adjust the steam-supply to the load on the engine for either forward or backward rotation of the crank by a simple movement of the reversing-lever *P*, which, in this case, operates the reversing-gears of both cylinders in Fig. 687.

2088. This class of engines, as a rule, however, are governed by hand, by making use of the throttle-valve shown at *J*, and operating it by the lever *K* to check the flow of the steam-supply, as in the case of the throttling governor. *H* is the main steam-supply pipe, and steam is admitted to both cylinders at the same pressure through the branch pipes *I* and *I'*.

2089. Hoisting-engines are said to be **first-motion engines** when the drum is fastened directly on the crank-shaft, as shown in Fig. 687, and **second-motion engines** when the rotary motion is imparted to the drum through the medium of a small gear-wheel fastened on the crank-shaft, which meshes with a large gear-wheel on the drum-shaft.

HAULAGE-ENGINES.

2090. Haulage-engines, as in the case of hoisting-engines, usually consist of two single-cylinder engines of exactly similar dimensions, taking steam from the same source, and at the same pressure. They are placed side by side, transmit power through the same shaft, and have their cranks at right angles to each other. There are, however, slight differences in the conditions under which these engines operate in the "tail-rope" and "endless-rope" systems, which necessitate slight differences in their construction and operation.

2091. The **tail-rope haulage-engine** is one of exactly the same type as the hoisting-engine already engine; therefore, it is operated at a constant speed and is regulated by a throttling or automatic governor.

FAN-ENGINES.

2093. Fan-engines do not of themselves form a separate and distinct class which may be considered under this head on account of any marked peculiarity of construction which they possess. We may employ, in the driving of a fan, any engine which is capable of developing the necessary amount of power to operate the fan at the required speed. It is, therefore, evident that such an engine may be of either the simple, duplex, compound, or other form, its type being usually determined by a careful consideration of the power it is to develop and the pressure under which it is to be operated.

COMPOUND ENGINES.

2094. Compound engines are those having two cylinders of which the working lengths are the same, but the diameter of one, the **high-pressure cylinder,** is less than that of the other, the **low-pressure cylinder.** In these engines the expansion of the steam is only partially effected in the high-pressure cylinder, and on being exhausted from it, passes into an intermediate chamber which serves as a reservoir, called the *receiver*, from which the low-pressure cylinder draws its supply of steam. In the low-pressure cylinder the expansion of the steam is continued and completed; and from here it either passes into the open air or into a condenser.

2095. The chief advantage of compounding is that a greater range of expansion can be obtained than is economical in a single cylinder. With a great range of expansion there is a correspondingly great difference in the temperature of the steam from the boiler and the temperature of the exhaust. The walls of the cylinder are alternately heated by the hot steam, a part of which condenses by the process, and cooled by the exhaust. The heat taken from the cylinder walls and carried away by the exhaust is almost a total loss. By allowing the steam to expand successively in two or more cylinders, the range in temperature in each cylinder is reduced. This reduces the quantity of steam condensed in the cylinder and the quantity of heat carried out by the exhaust.

2096. The **tandem-compound engine,** shown in Fig. 690, is one of the most common types of the stationary compound engine. In this type the high-pressure cylinder *a* is usually placed directly behind the low-pressure cylinder *b*, both pistons being connected to the same piston-rod. The exhaust of the high-pressure cylinder is carried in any

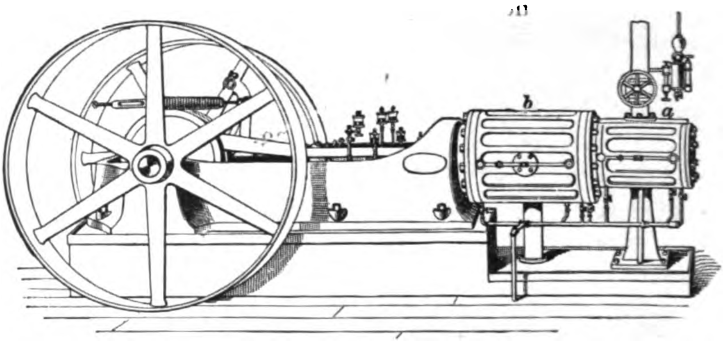


FIG. 690.

convenient manner to the low-pressure cylinder, but the more direct the conducting passages are, the better. This form of construction has one great advantage of furnishing a comparatively cheap method of compounding, as the extra cost is only a little more than that of the additional cylinder and its valve-gear. Being compact, it also takes up but very little more room than a single-cylinder engine.

2097. **Cross-compound** engines are those in which the two cylinders, each being in itself a complete engine, just as in the case of the duplex hoisting and haulage engines already described, are placed side by side and have their cranks connected at right angles on a common shaft. In this case, as above, the steam from the high-pressure cylinder is exhausted into a receiver or chamber from which the low-pressure cylinder draws its steam-supply without seriously affecting the working of the steam. This class of engine has the advantage over the tandem type of running much smoother on account of the more perfect balancing of the rotating parts. It is generally used in large constructions where the tandem type would not be practicable. In compound engines, the initial steam-pressure ranges from 60 to 125 pounds per square inch, with ratios of expansion varying from 3 to 11.

2098. Triple-expansion engines are three-cylinder compound engines. In these, high initial pressures of from 120 to 250 pounds per square inch and ratios of expansion varying from 9 to 27 are used. As in the case of the compound engine, the steam passes through each of the three cylinders of the triple-expansion engine before being finally expelled. As a general rule, engines of this type are employed only where a large amount of power is required.

2099. Single-acting engines are those which take steam during only one of the two strokes of a revolution; that is, steam is admitted to the cylinder during the forward stroke of the piston, but is shut off during the return stroke.

AIR AND AIR COMPRESSION.

PNEUMATICS.

INTRODUCTION.

2100. In order to understand the various operations of tunneling, rock-drilling, pumping, mine ventilation, etc., which depend for their success upon the physical properties of air, a knowledge of the leading principles of the properties of air and gases is necessary. That branch of mechanics which treats of the physical properties of air and gases is called **Pneumatics.**

2101. The most striking feature concerning gases is that, *no matter how small the quantity may be, they will always fill the vessels which contain them.* If a bladder or football be partly filled with air, and placed under a glass jar (called a receiver), from which the air has been exhausted, the bladder or football will immediately expand, as shown in Fig. 691. The force which a gas always exerts, when confined, on the vessel which contains it, is called **tension.** The word tension in this case means pressure, and is used in this sense only in reference to gases.

FIG. 691.

NOTE.—The student who is not already familiar with the elementary properties of air should read Arts. **2153** to **2168,** at the end of this section, before proceeding further.

2104. Magdeburg Hemispheres.—By means of the two hemispheres shown in Fig. 694, it can be proven that the atmosphere presses upon a body equally in all directions. They were invented by Otto Von Guericke, of Magdeburg, and are called the **Magdeburg hemispheres.** One of the hemispheres is provided with a stop-cock, by which it can be screwed on an air-pump. The edges fit accurately and are well greased, so as to be air-tight. As long as the hemispheres contain air, they can be separated without trouble; but when the air in the interior is pumped out by means of an air-pump, they can be separated only with great difficulty. The force required to separate them will be equal to the area of the largest circle of the hemisphere in square inches, multiplied by 14.7 pounds. This force will be the same in whatever position the hemisphere may be held, thus proving that the pressure of air upon it is the same in all directions.

Fig. 694.

2105. The pressure of the atmosphere is very clearly shown by means of an apparatus like that illustrated in Fig. 695. Here a cylinder fitted with a piston is held in suspension by a chain. At the top of the cylinder is a plug *A*, which can be taken out. This plug is removed, the piston pushed up (the force necessary being equal to the weight of the piston and rod *B*), until it touches the cylinder-head. The plug is then screwed in, and the piston will remain at the top until a weight has been hung on the rod equal to the area of the piston, multiplied by 14.7 pounds, less the weight of the piston and rod. If a force was applied to the rod sufficiently great to force the piston downwards, it would raise any weight less than the above to the top of the cylinder. Suppose the weight to be removed, and the piston to be supported, say, midway of the length of the cylinder. Let the plug be removed and air admitted above the piston, then screw the plug back into its place; if the piston be shoved upwards, the farther up it goes, the greater will be the force necessary to push it, on account of the compression of the air. If the piston is of large diameter, it will also require a great force to pull it out of the cylinder, as a little consideration will show. For example, let the diameter of the piston be 20 inches, the length of the cylinder 36 inches, plus the thickness of the piston, and the weight of the piston and rod 100 pounds. If the piston is in the middle of the cylinder, there will be 18 inches of space above it, and 18 inches of space below it. The area of the piston is $20^2 \times .7854 = 314.16$ square inches, and the atmospheric pressure upon it is $314.16 \times 14.7 = 4,618$ lb., nearly. In order to shove the piston upwards 9 inches, the pressure upon it must be twice as great, or 9,236 pounds, and to this must be added the weight of the piston and rod, or $9,236 + 100 = 9,336$ lb. The force necessary to cause the piston to move upwards 9 inches would then be $9,336 - 4,618 = 4,718$ lb. Now, suppose the piston to be moved downwards until it is just on the point of being pulled out of the cylinder. The volume above it will then be twice as great as before, and the pressure one-half as great, or $4,618 \div 2 = 2,309$ lb. The total upward pressure will be the pressure of the atmosphere less the weight of the piston and rod, or $4,618 - 100 = 4,518$ lb., and the force necessary to pull it downwards to this point will be $4,518 - 2,309 = 2,209$ lb.

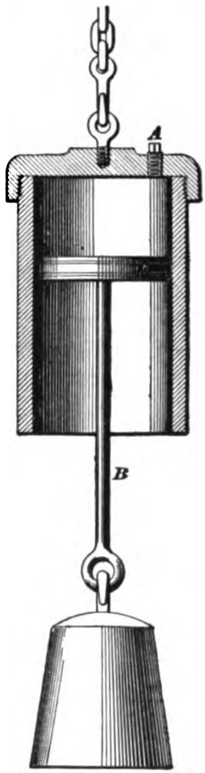


FIG. 695.

2106. The Injector.—A section of an injector is shown in Fig. 696. There are many different kinds of these is formed which permits the pressure of the atmosphere to force water through *P* until it finally fills the passages and flows out through *L* and the overflow nozzle *O*. As soon as water appears at *O*, the valve *R* is closed and the main steam-valve *A* is opened by the wheel *S*, thus admitting steam to the passages *C*, *H*, *K*. This steam draws water from *G* through the opening surrounding *H* and discharges it through *K* with such a high velocity that it rushes past the opening *T* into the nozzle *M* and thence into the boiler.

THE EXPANSION OF AIR AND GASES.

2108. When a gas expands, it does work; when it is compressed, work is required to be done upon the gas to compress it. Suppose that a cubic foot of air is confined in a vessel having an area of 1 square foot and a length of 5 feet plus the thickness of the piston, so that the piston can move 5 feet. Suppose the piston to be in the position shown in Fig. 697; that the absolute pressure of the volume of air enclosed in the cylinder is 100 lb. per square inch on the piston, and that the temperature is 150°.

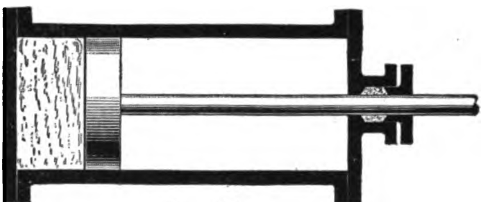


FIG. 697.

Since the area of the piston is 1 square foot, the volume of the enclosed air is 1 cubic foot. Now, let this air expand, and keep the temperature constant by adding heat to it. The piston will move ahead; the atmospheric pressure upon it will be overcome through the distance it moves; the volume of the air will increase and the pressure decrease, according to Mariotte's Law. When the piston has moved 1 foot, the volume will be 2 cubic feet, and the pressure is found by the formula to be $p_1 = \frac{1 \times 100}{2} =$ 50 lb. per square inch. When the piston has moved 2 feet, the pressure is $\frac{100}{3} = 33\frac{1}{3}$ lb. per square inch, etc. To show, graphically, the effects of this expansion upon the pressure

$$88.9 + 72.7 + 61.5 + 53.3 + 47.1 + 42.1 + 38.1 + 34.8 + 32 + 29.6 + 27.6 + 25.8 + 24.2 + 22.9 + 21.6 + 20.5 = 642.7.$$

$$642.7 \div 16 = 40.17 \text{ lb. per sq. in.}$$

$$144 \times 40.17 \times 4 = 23{,}138 \text{ foot-pounds, nearly.}$$

A sufficiently close result for all practical purposes can be obtained by dividing $AEFL$ into 10 parts.

2110. The curve shown in Fig. 698 is called the **isothermal expansion curve,** or the **expansion curve of constant temperature.** It is known in mathematics as the **equilateral hyperbola,** and, hence, when used on indicator-diagrams, is sometimes called the **hyperbolic curve of expansion.**

2111. If the air or gas were compressed, the action would be exactly the reverse of the expansion. Heat would have to be abstracted instead of added; the pressure would increase instead of decreasing, and the volume decrease instead of increasing.

In Fig. 700, let EF represent the initial pressure = 20 lb. per sq. in., OF the initial volume = 5 cu. ft. As the volume decreases, the pressure will increase, as indicated by the curve $EDCBA$, when the temperature is kept constant.

2112. Suppose that a volume of air expands from the same initial volume and pressure as in the case of Fig. 698, but that no heat is added or taken away; the temperature will fall; the pressure will fall much faster than in the case of isothermal expansion. If the air be compressed as in Fig. 700, and no heat is added or taken away, the temperature will rise; the pressure will increase much faster than in the case of isothermal compression. The formula which expresses this change of pressure and volume requires a table of logarithms in order to calculate the values; for this reason, the formula will not be given here. The work which the air can do when expanding under these conditions is considerably less than when it expands isothermally. In order to show this difference between the two cases, the pressures have been calculated which correspond to the said to expand **adiabatically.** The curved line *A B C D E* is called the **adiabatic curve.**

If the volume of air was 5 cu. ft., and the pressure was 10.34 lb. per sq. in.; that is, if the piston was at *E F*, Fig. 701, and it was compressed to 1 cu. ft., and no heat lost, the final pressure would be 100 lb. as before; the curve of pressures would be the adiabatic curve *A B C D E*, as in the case of expansion. The work which this air would do

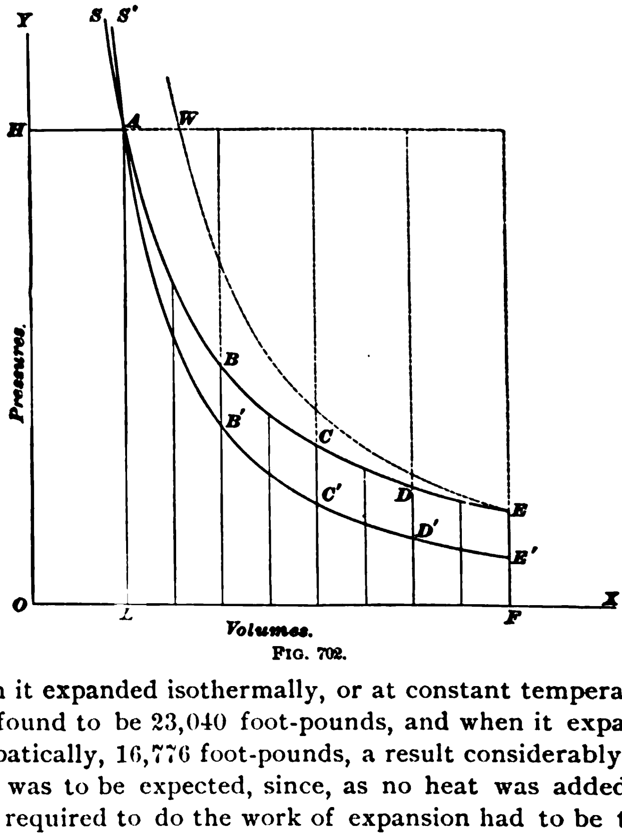


FIG. 702.

when it expanded isothermally, or at constant temperature, was found to be 23,040 foot-pounds, and when it expanded adiabatically, 16,776 foot-pounds, a result considerably less. This was to be expected, since, as no heat was added, the heat required to do the work of expansion had to be taken from the gas, thus reducing its energy and the amount of work that it could do. To better show the effects of isothermal and adiabatic expansion, the two curves shown in Figs. 698 and 701 are drawn together in Fig. 702. Here, point where the air is used, and the air has to be transmitted to that point through 1,000 feet or more of pipe, it cools down to the temperature of the outside air; its pressure falls in consequence of this loss of heat, and there is a very considerable loss of power. Add to this the friction of the engine and compressor, a slight loss through friction of the air in the pipe, and the loss through leakage; the result is that, even when the air has been cooled to a greater or less extent, according to the type of compressor, the efficiency averages about 50%, being above that in some plants and below in others. By *efficiency* is meant the ratio of the work obtained from the air to the work done in compressing it. The first can be obtained when the pressure and amount of air used in a given time is known, and the last is found from the indicator-card of the steam-engine, or by other means if some other motor is used. Thus, suppose that the indicated horsepower of the steam-cylinder is 23.45 and the power obtained from the compressed air is 13.8 horsepower, the efficiency would be $\frac{13.8}{23.45} = .5885$, or 58.85%.

Unless the air is cooled during compression, or some other device (to be described farther on) is employed, the efficiency will fall below the 50% average given above.

TYPES OF AIR-COMPRESSORS.

WET COMPRESSORS.

2120. There are two systems in use by which it is attempted to absorb the heat developed during compression. They are so different in their methods of cooling and in the results obtained that it is usual to make two distinct classes of them, viz., *wet compressors* and *dry compressors*.

2121. A **wet compressor** is one in which the water is introduced directly into the air-cylinder, and thus brought into contact with the air. It is made in two forms; in one, the water is injected into the cylinder in the form of a finely divided spray, thus mixing thoroughly with the air; in the *d'* is raised, and the air passes out and is discharged through the delivery-pipe *C* into a conduit. Any excess of water is also discharged through the valve *d'* into the conduit, but is collected and forced back into the cylinder through the nozzles *E* and *E'*.

Suppose the piston to be on the return stroke. The valve *d'* falls; the weight of the water causes it to fall and follow up the piston, leaving a vacuum behind it. The pressure of the atmosphere against the left side of the valve *v'* forces it to the right, and, with it, the valve *v* against its seat. The air then flows in and follows up the piston on the right side and is compressed on the left side, the operation being repeated exactly as before described. It will be noticed that both discharge-valves open into the same delivery-pipe *C*. This is called a **double-acting compressor,** because the air is compressed on both sides of the piston, that is, twice during each revolution of the crank-pin.

2123. In Fig. 704 is shown an elevation and section through the air-cylinder of a **Burleigh single-acting vertical air-compressor.** Only one cylinder is seen in the cut, but there are two more behind the one shown—an air-cylinder, and a steam-cylinder to drive the compressor. The cranks of the air-cylinders are set directly opposite each other, so that they are on the opposite dead-points at the same instant. The air is compressed during the upward stroke, and admitted during the downward stroke. The piston has a large valve *V* in it which is raised during the downward stroke, allowing the free air to enter and fill the cylinder; at the same time, water is injected through the pipe *S*. The water is not sprayed in during compression, as in the compressor previously described. It nearly fills the clearance space, and cools the air somewhat by reason of cooling the cylinder walls and compelling the air to come into contact with it when resting on top of the piston during the up stroke. The discharge-valve *d* is raised when the pressure reaches the desired point, the air passing out through the delivery-pipe *C*.

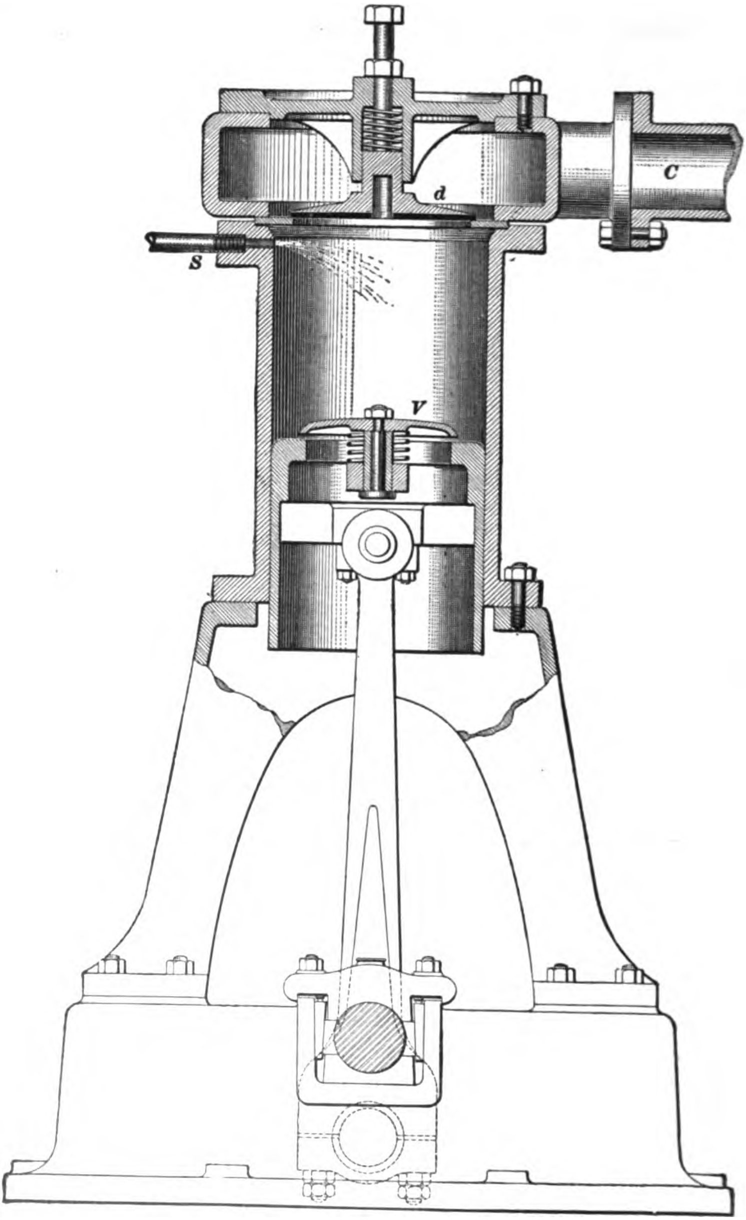


FIG. 704.

walls, which, in turn, cool the air. This method of cooling

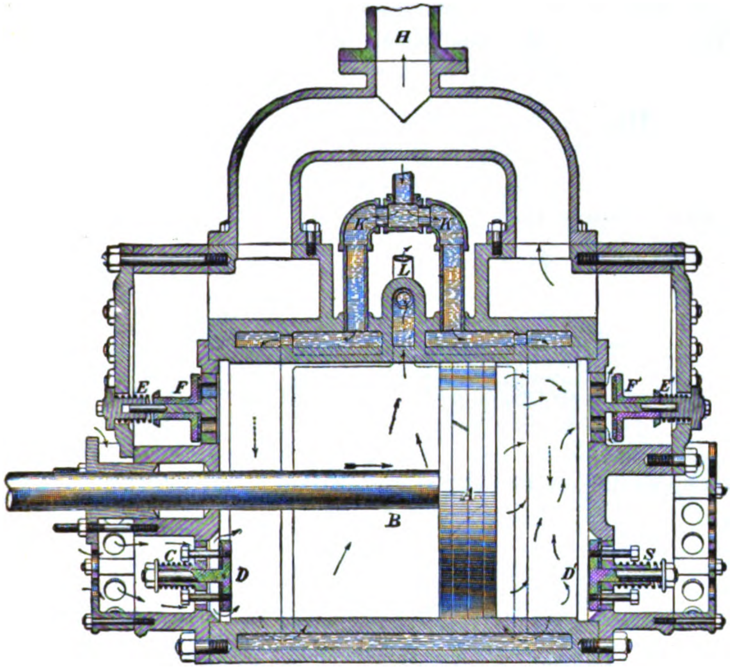


FIG. 707.

by having the water circulate around the hollow cylinder walls is termed a **water-jacket.**

2129. The clearance space has been mentioned several times in the preceding pages, as if it exerted a prejudicial effect upon the working of the compressor. To show the effect which it really produces, assume that the air has been compressed isothermally. In this case, there would be a certain loss of power, owing to heat having been produced and then absorbed by the cooling methods employed. As part of the air was not discharged, the work required to heat this air has been lost. Had the air been compressed adiabatically, the extra heat due to compression retained by the air in the clearance space is given up during the return stroke, and assists in the work of compression. The best holes of the lugs, so that a slight forward or backward movement of the ring can be obtained. These rings form the inlet-valves, and operate as follows: Suppose that the piston is moving in the direction indicated by the arrow on the piston-rod. The right-hand side valve *B* is open; the left-hand side valve *B* is closed by reason of the pressure of the compressed air acting against it. The free air enters the piston through the tube *A*, and flows out through the right-hand side inlet-valve *B* into the cylinder. When the proper pressure has been reached, the delivery-valve *E* opens, and the air is discharged, following the direction indicated by the arrows, out through the pipe *F*. When the piston reaches the end of its stroke, and reverses, the valves *B* tend to continue in the former direction, according to Newton's first law of motion; hence, their inertia causes the right-hand valve to be thrown against its seat, and the left-hand valve to open. The operation above described is again repeated, except that the free air now flows through the left-hand inlet-valve, and the compressed air is discharged through *G*.

The air is cooled by means of a water-jacket, the walls being hollow and the water flowing around them, entering through *H* and flowing out through *I*. *K* is a drain-pipe supplied with a valve, and is for the purpose of draining the water from the cylinder. As there are no suction-valves in the ends of the cylinder, the greater part of the cylinder-heads is also water-jacketed. Oil drops through the small orifice *J*, and lubricates the cylinder. The clearance is reduced to a very small fraction of the cylinder volume, and the compressor can be run at as high a speed as desired.

DUPLEX COMPRESSORS.

2131. With the exception of the Burleigh, all of the compressors previously described have been what are termed **straight-line compressors**; that is, the center lines of the steam and air cylinders have formed one straight line. When two straight-line air-compressors are placed side by side, having a common crank-shaft, they are called **duplex**

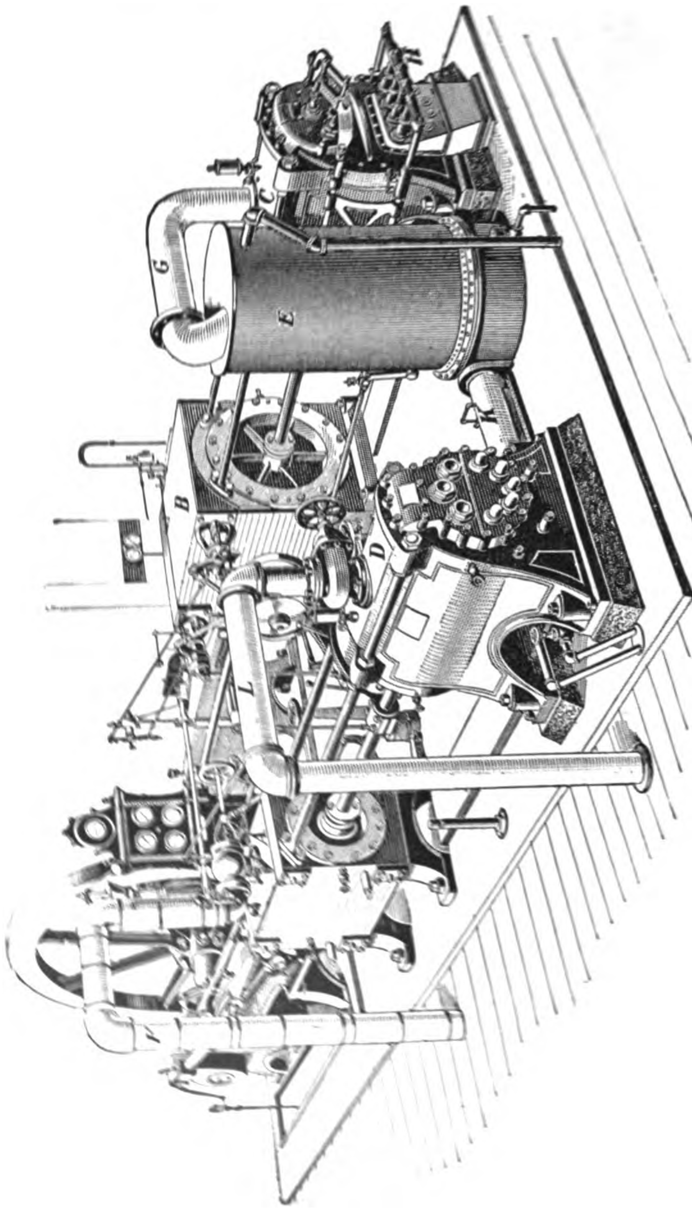


FIG. 714.

built by the same company, which differs from the other, from the fact that it is driven by a tandem-compound steam-engine. All four cylinders are in the same straight line. *A* is the high and *B* the low pressure steam-cylinder; *C* and *D* are the corresponding air-cylinders. *E* is the inter-cooler, which is partly filled with pipes through which the cold cooling water circulates. These pipes divide the air-current into small streams, and enable nearly every particle to come into contact with the cold surface, thus reducing the temperature very rapidly. *F* is the cross-head, and *G* one of the two fly-wheels. In this compressor, all of the advantages are obtained that are characteristic of the tandem-compound type of engine, together with those to be derived from the compound compressor previously described; in other words, the consumption of steam is reduced, and the strains are far more equally distributed throughout the stroke.

2138. A **Rand duplex-compound air-compressor** driven by a **Corliss cross-compound condensing steam-engine** is shown in Fig. 714. *A* and *B* are the high and low pressure steam-cylinders, *F* being the steam-pipe; *C* is the low-pressure air-cylinder. Air enters each end of the cylinder alternately. The inlet-valves *H* are actuated positively by a combination of levers and yokes, no springs being used. The air is here compressed to almost 30 pounds, and then discharged through the pipe *G* into the inter-cooler *E*, where the temperature is reduced by means of coiled pipes through which cold water circulates. From the inter-cooler, the air is conducted through the pipe *K* into the high-pressure cylinder *D*, where it is further compressed to the required pressure and discharged through the pipe *L* into the receiver.

2139. Fig. 715 shows a plan and side elevation of a duplex air-compressor driven by water. The fly-wheel *F* has a large number of cup-shaped projections on its rim. The water is conducted to the wheel by the pipe *A*, discharging at a high velocity and striking the cup-shaped the compression-cylinder, and delivers it to the hoist, pump, or drill with great regularity of pressure, in much the same manner that a boiler delivers steam to an engine. In designing receivers, when the compressed air is to be used for driving rock-drills, it is customary to allow about ten cubic feet of receiver-volume for each drill; i. e., for five drills, the volume of the receiver would be about 50 cubic feet. In all cases, the larger the receiver, the better.

2141. In Fig. 716 is shown a **horizontal air-receiver,** and in Fig. 717 a **vertical air-receiver.** The air enters

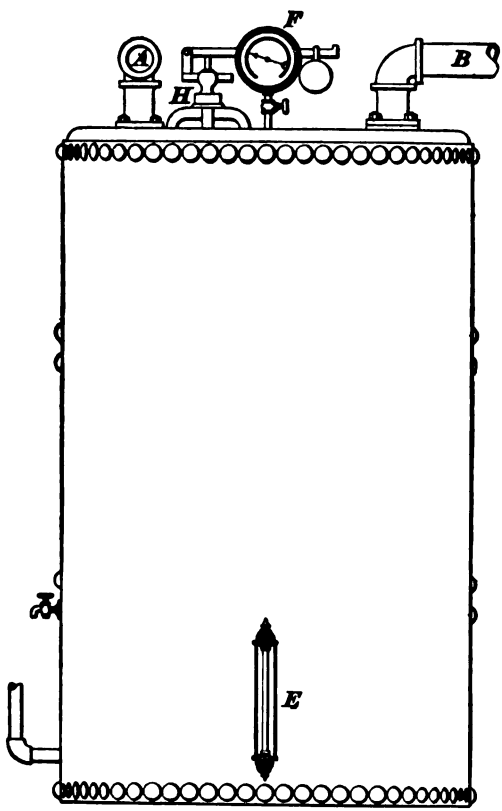


FIG. 717.

the receiver at *A*, flows through a series of pipe-coils, and down. Above the valve is a small cylinder *B*, having a piston connected to the valve below by the stem *C*. At the side of this cylinder is a small spring safety-valve *D*, the under side of which connects with the receiver by a pipe. The hand-wheel *E* varies the tension of the spring so that the pressure in the receiver can be adjusted as desired. When the pressure in the receiver has reached the desired limit, the safety-valve *D* allows the air to escape and pass into the small cylinder *B*, beneath the piston; if no escape was provided, the piston would be driven to the top of the cylinder, the valve in *A* would be held to its seat, and the engine stopped. To prevent this, a very fine slot is cut in the side of the small cylinder *B*. When the piston rises, it uncovers this slot, and thus furnishes an escape for the air which is passing the safety-valve. If only a little air passes the valve, a small part of the slot will accommodate it, and the piston will take a low position, the speed of the engine being then but slightly reduced. If more air escapes, the piston will rise higher, in order to allow more of the slot to be uncovered, and thus provide a larger opening for the exit of the air, the engine speed being still further reduced. That the engine may be prevented from entirely stopping, a screw-stop *F* is placed on the top of the cylinder *B*; this prevents the valve in *A* from closing more than is sufficient to run the engine at the slowest speed that will carry it over the dead-centers.

INDICATOR-CARDS.

2143. In Fig. 719 are shown two indicator-cards, one taken from the steam-cylinder and the other from the air-cylinder. The most striking characteristic of these cards is that the pressure of the discharged air is considerably higher than the initial pressure of the steam. The area of the two cards is very nearly the same, that of the air card being a little less; this shows that the work done in both cylinders is practically the same, the extra work shown by the steam card being used to overcome the engine friction. The extra energy of the steam in the first half of the stroke where of the free air actually compressed. Theoretically, this volume is equal to the area of the piston, multiplied by the length of the stroke. Actually, however, owing to imperfections in workmanship, the air does not begin to compress at the instant the piston begins its stroke. The point where the compression begins is indicated on the diagram by the point *A*, where the compression-curve begins to leave the atmospheric line *B C*. The length of the stroke is proportional to the length of the atmospheric line *B C*. The ratio

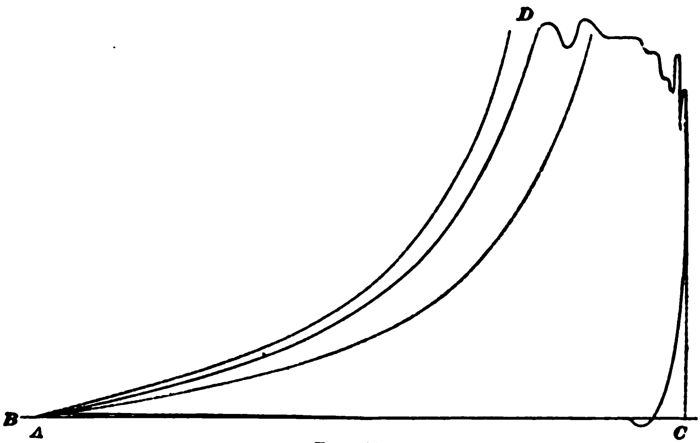


FIG. 720.

of the lengths of *B A* to *B C* will give the percentage of theoretical volume lost. In this case, $\frac{B\,A}{B\,C} = .034$, nearly, $= 3.4\%$.

REHEATING COMPRESSED AIR.

2144. Air can, of course, be expanded exactly like steam when used as a motive power, and the gain through expansion is nearly as great as in the case of steam. The chief difficulty lies in the intense cold produced by air, at a high pressure and normal temperature, expanding down to the pressure of the atmosphere. Thus, if a cubic foot of air at a temperature of 60° and a pressure of 88.2 pounds be expanded adiabatically, performing work, to the pressure of the atmosphere, the resulting temperature will be 151° below donc in the cylinder of the engine itself, which the compressed air drives, and that during expansion (a scheme which has not yet been realized practically), there will be no increase in pressure. This is because air expands when heated, and unless prevented from expanding, the pressure will not increase. The very long column of air behind that which is being reheated acts like an elastic cushion, and the increase of volume is so slight compared with the whole volume in the pipe and receiver that the increase in pressure is not perceptible. The explanation of the increase of work lies in the fact that all work obtained from air, steam, or gas, when used as a motion-producer, is derived from the amount of heat contained in it. When the air is heated, almost the entire amount of heat generated by the combustion is converted directly into work, while in the best steam-engines not more than 12% to 13% of the heat energy of the coal is converted into work.

2148. Fig. 723 shows a reheater in which the air is brought into contact with the fuel. This illustration is taken from a case which was put into actual service in connection with a rock-drill. Immediately above the throttle-valve *A*, and near the steam (air) chest *B* of the rock-drill, was placed an enlarged pipe-fitting *C*, in the interior of which, a little above the center, was fixed a piece of wire gauze *D*; above this gauze, charcoal *F* was thrown, some of it being in an incandescent state. The whole chamber was closed and the compressed air turned on. The air thus brought into direct contact with the burning charcoal was admitted into the drill-cylinder extremely hot.

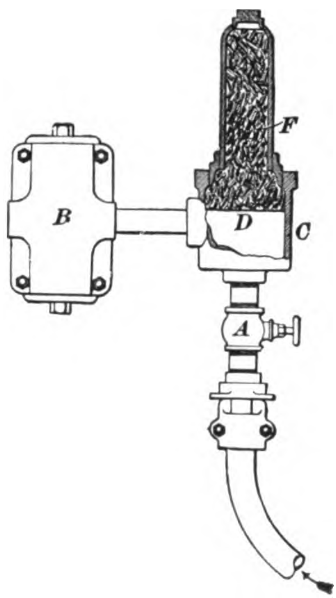


FIG. 723.

Instead of charcoal, a substance called **sestalit** has been used with considerable success, the advantage of sestalit being that it remains ignited for some length of time after the air has been shut off, and the products of combustion are not objectionable when discharged in a confined space.

2149. Fig. 724 shows an electric reheater. *C* is the air-compressor, the compressed air being conveyed through a pipe to the receiver *D*, and thence by means of the

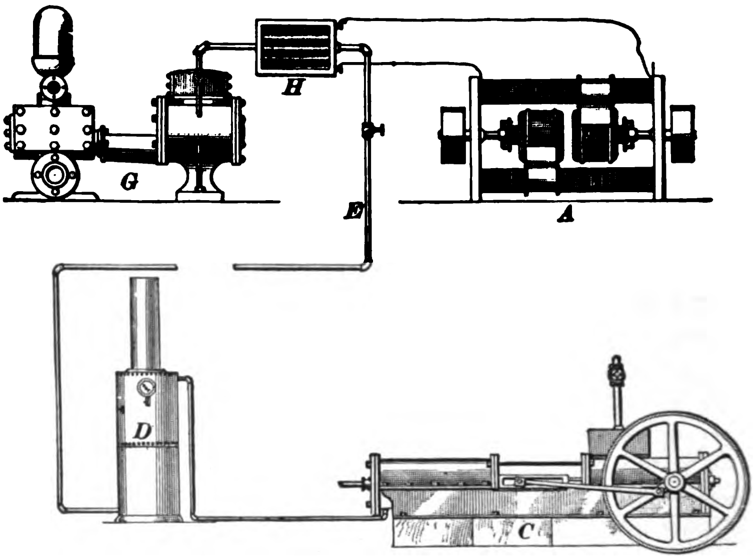


Fig. 724.

pipe *E* to the pump *G*, which is driven by compressed air, and is situated, say, a mile from the compressor. A dynamo *A*, which serves to light the mines, is situated in the engine-room, near the compressor. Near the pump a resistance-coil *H* is placed in a chamber through which the compressed air must pass before entering the pump-cylinder. This resistance-coil is made of some highly refractory substance, which resists the passage of the current to such an extent that the electrical energy is converted into heat, and thus heats the air. This reheater has many advantages. There being no combustion, it is perfectly safe in mines filled with inflammable gases, and the ease with which it is applied or stopped by simply opening or closing a switch also recommends it. It is a cheap device, and has been recently employed in the shape of a simple coil of wire placed in the air-pipe. Since the loss of electric energy is slight compared with the loss of pressure in the compressed air, the efficiency of the whole system is increased by using the electric wire to reheat the air. It is not, however, as economical as the reheater previously mentioned, but is in many cases more convenient, and for that reason preferable.

Experience has shown that air-engines do not work to advantage at higher temperatures than 350°; hence, the gain through reheating the air is limited. The cost of the fuel consumed during reheating is trifling. With the reheaters commonly used, where the air is heated directly through the combustion of charcoal, it amounts to from one to two cents per horsepower per day. The gain is considerable, and they should be used when practicable.

THE CALCULATION OF THE SIZE OF AN AIR-COMPRESSOR.

2150. It is required to determine the size of the steam and air cylinders of a duplex air-compressor to furnish the compressed air necessary to drive a pump and a set of rock-drills, 28 horsepower being necessary to drive them. To calculate this problem accurately is very tedious and difficult. Moreover, it requires a good knowledge of the application of logarithms and also of higher mathematics to approach the subject with any degree of success. Such being the case, the following approximate method will give results close enough for ordinary practice. The loss of power, in common practice, where compressed air is used to drive machinery in mines and tunnels, is about 70% when common American air-compressors are used and the air is transmitted far enough to lose the heat imparted to it by compression. Where the best compressors are used, the loss is about 60%. In both cases, it is assumed that the air

PHYSICAL PROPERTIES OF AIR AND GASES.

2153. Air is a mechanical mixture of two gases, nitrogen and oxygen, and contains about three parts, by weight, of the former, to one of the latter. As *water* is the most common type of fluids, so *air* is the most common type of gases. It was supposed by the ancients that air had no weight, and it was not until about the year 1650 that it was proven that air really has weight. A cubic inch of air, under ordinary conditions, weighs .31 grain, nearly. The ratio of the weight of air to water is about 1 : 774; that is, air is only $\frac{1}{774}$ as heavy as water. If a vessel made of light material be filled with a gas lighter than air, so that the total weight of the vessel and gas is less than the air they displace, the vessel will rise. It is on this principle that balloons are made.

2154. Since air has weight, it is evident that the enormous quantity of air that constitutes the atmosphere must exert a considerable pressure upon the earth. This is easily proven by taking a long glass tube closed at one end and filling it with mercury. If the finger be placed over the open end so as to keep the mercury from running out, and the tube be inverted and placed in a glass of mercury, as shown in Fig. 725, the mercury in the tube will fall, then rise, and, after a few oscillations, will come to rest at a height above the top of the mercury in the glass equal to about 30 inches. This

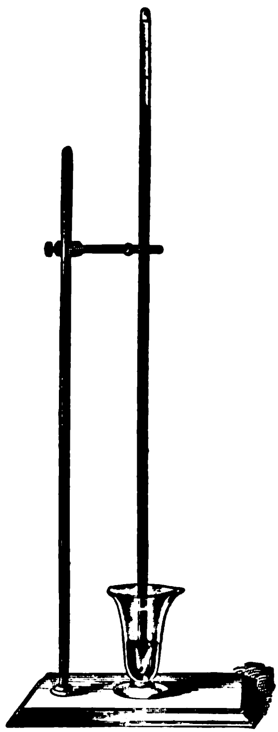


FIG. 725.

were 14 inches of vacuum, etc. Hence, when the vacuum-gauge of a condensing-engine shows 26 inches of vacuum, there is enough air in the condenser to produce a pressure of $\frac{30 - 26}{30} \times 14.7 = \frac{4}{30} \times 14.7 = 1.96$ pounds per square inch.

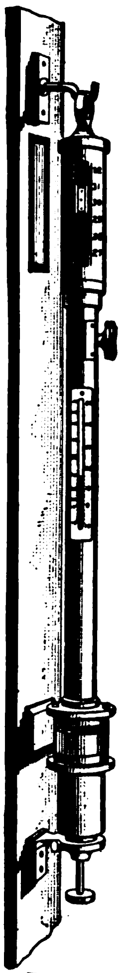


FIG. 726.

If the tube had been filled with water instead of mercury, the height of the column of water to balance the pressure of the atmosphere would have been $30 \times 13.6 = 408$ inches $= 34$ feet. This means that if a tube be filled with water, inverted, and placed in a dish of water in a manner similar to the experiment made with the mercury, the height of the column of water would be 34 feet.

2156. The **barometer** is an instrument used for measuring the pressure of the atmosphere. There are two kinds in general use, the mercurial barometer and the aneroid barometer. The *mercurial barometer* is shown in Fig. 726. The principle is the same as the inverted tube, shown in Fig. 725. In this case, the tube and cup at the bottom are protected by a brass or iron casing. Near the top of the tube is a graduated scale which can be read to $\frac{1}{1000}$ of an inch by means of a vernier. Attached to the casing is an accurate thermometer for determining the temperature of the outside air at the time the barometric observation is taken. This is necessary, since mercury expands when the temperature is increased, and contracts when the temperature falls; for this reason, a standard temperature is assumed, and all barometer readings are reduced to this temperature. This standard temperature is usually taken at 32° F., at which temperature the height of the mercurial column is 30 inches. Another correction is made for the altitude of the place above sea-level, and a third correction for the effects of capillary attraction.

floor. The mercurial barometer is the standard. With air, as with water, the lower we get, the greater the pressure, and the higher we get, the less the pressure. At the level of the sea, the height of the mercurial column is about 30 inches; at 5,000 feet above the sea, it is 24.7 inches; at 10,000 feet above the sea, it is 20.5 inches; at 15,000 feet, it is 16.9 inches; at 3 miles, it is 16.4 inches, and at 6 miles above the sea-level, it is 8.9 inches.

2157. Density of Air.—The weight of a cubic foot (called the **density**) also varies with the altitude; that is, a cubic foot of air at an elevation of 5,000 feet above the sea-level will not weigh as much as a cubic foot at sea-level. This is proven conclusively by the fact that at a height of 3½ miles the mercurial column measures but 15 inches, indicating that half the weight of the entire atmosphere is below that. It is known that the height of the earth's atmosphere is at least 50 miles; hence, the air just before reaching the limit must be in an exceedingly rarefied state. It is by means of barometers that great heights are measured. The aneroid barometer has the heights marked on the dial, so that they can be read directly. With the mercurial barometer, the heights must be calculated from the reading.

2158. Atmospheric Pressure.—The atmospheric pressure is everywhere present, and presses all objects in all directions with equal force. If a book is laid upon the table, the air presses upon it in every direction with an equal average force of 14.7 pounds per square inch. It would seem as though it would take considerable force to raise a book from the table, since, if the size of the book were 8 inches by 5 inches, the pressure upon it is $8 \times 5 \times 14.7 = 588$ pounds; but there is an equal pressure beneath the book to counteract the pressure on the top. It would now seem as though it would require a great force to open the book, since there are two pressures of 588 pounds each, acting in opposite directions, and tending to crush the book; so it would but for the fact that there is a layer of air between each leaf acting upwards and downwards with a pressure of

14.7 pounds per square inch. If two metal plates be made as perfectly smooth and flat as it is possible to get them, and the edge of one be laid upon the edge of the other, so that one may be slid upon the other, and thus exclude the air, it will take an immense force, compared with the weight of the plates, to separate them. This is because the full pressure of 14.7 pounds per square inch is then exerted upon each plate, with no counteracting equal pressure between them.

If a piece of flat glass be laid upon a flat surface that has been previously moistened with water, it will require considerable force to separate them; this is because the water helps to fill up the pores in the flat surface and glass, and thus creates a partial vacuum between the glass and the surface, thereby reducing the counter-pressure beneath the glass.

2159. Tension of Gases.—In Fig. 725, the space above the column of mercury was said to be a vacuum, and that if any gas or air was present it would expand, its tension forcing the column of mercury downwards. If enough gas is admitted to cause the mercury to stand at 15 inches, the tension of the gas is evidently $\frac{14.7}{2} = 7.35$ pounds per square inch, since the pressure of the outside air of 14.7 pounds per square inch balances only 15 inches, instead of 30 inches of mercury; that is, it balances only half as much as it would if there were no gas in the tube; therefore, the tension (pressure) of the gas in the tube is 7.35 pounds. If more gas is admitted, until the top of the mercurial column is just level with the mercury in the cup, the gas in the tube has then a tension equal to the outside pressure of the atmosphere. Suppose that the bottom of the tube is fitted with a piston, and that the total length of the inside of the tube is 36 inches. If the piston be shoved upwards so that the space occupied by the gas is 18 inches long, instead of 36 inches, the temperature remaining the same as before, it will be found that the tension of the gas within the tube is 29.4 pounds. It will be noticed that the volume occupied by the gas is only half that in the tube before the

SOLUTION.—(*a*) $v_1 = \frac{p\,v}{p_1} = \frac{5.6 \times 10}{4} = 14$ cubic feet. Ans.

(*b*) $v_1 = \frac{5.6 \times 10}{8} = 7$ cubic feet. Ans.

(*c*) $v_1 = \frac{5.6 \times 10}{25} = 2.24$ cubic feet. Ans.

(*d*) $v_1 = \frac{5.6 \times 10}{100} = .56$ cubic foot. Ans.

2161. As a necessary consequence of Mariotte's law, it may be stated that *the density of a gas varies directly as the pressure and inversely as the volume;* that is, *the density increases as the pressure increases, and decreases as the volume increases.*

This is evident, since if a gas has a tension of two atmospheres, or $14.7 \times 2 = 29.4$ pounds per square inch, it will weigh twice as much as the same volume would if the tension was one atmosphere, or 14.7 pounds per square inch. For, let the volume be increased until it is twice as great as the original volume, the tension will then be one atmosphere. The total weight of the gas has not been changed, but there are now 2 cubic feet for every 1 cubic foot of the original volume, and the weight of 1 cubic foot now is only half as great as before. Thus, the density decreases as the volume increases, and as an increase of pressure causes a decrease of volume, the density increases as the pressure increases.

Let D be the density corresponding to the pressure p and volume v, and D_1 be the density corresponding to the pressure p_1 and volume v_1. Then,

$$p : D :: p_1 : D_1, \text{ or } p\,D_1 = p_1\,D, \qquad \textbf{(152.)}$$

and $$v : D_1 :: v_1 : D, \text{ or } v\,D = v_1\,D_1. \qquad \textbf{(153.)}$$

2162. Since the weight is proportional to the density, the weights may be used in place of the densities in formulas **152** and **153.** Thus, let W be the weight of a quantity of air or other gas whose volume is v and pressure is p; let W_1 be the weight of the same quantity when the volume is v_1 and pressure is p_1. Then,

$$p : W :: p_1 : W_1, \text{ or } p\,W_1 = p_1\,W; \qquad \textbf{(154.)}$$

$$v : W_1 :: v_1 : W, \text{ or } v\,W = v_1\,W_1. \qquad \textbf{(155.)}$$

Let P = pressure of air per square inch;
V = volume of air in cubic feet;
T = absolute temperature of air;
W = weight of air in pounds.

Then,
$$P = \frac{.37052\,W\,T}{V}; \quad (158.)$$

$$V = \frac{.37052\,W\,T}{P}; \quad (159.)$$

$$T = \frac{P\,V}{.37052\,W}; \quad (160.)$$

$$W = \frac{P\,V}{.37052\,T}. \quad (161.)$$

Example.—If 40 cubic feet of air weigh 3.5 pounds, and have a temperature of 82°, what is the pressure (tension) in pounds per square inch?

Solution.— $P = \frac{.37052\,W\,T}{V} = \frac{.37052 \times 3.5 \times 541}{40} = 17.539$ lb. per sq. in. Ans.

Example.—What is the volume in cubic feet of a certain quantity of air having a tension of 17.539 pounds per square inch, a temperature of 80°, and which weighs 3.5 pounds?

Solution.— $V = \frac{.37052\,W\,T}{P} = \frac{.37052 \times 3.5 \times 541}{17.539} = 40$ cu. ft. Ans.

Example.—If 40 cubic feet of air having a tension of 17.539 pounds per square inch weigh 3.5 pounds, what is the temperature?

Solution.— $T = \frac{P\,V}{.37052\,W} = \frac{17.539 \times 40}{.37052 \times 3.5} = 541°$, nearly. Hence, $541° - 459° = 82°$. Ans.

Example.—If 40 cubic feet of air have a tension of 17.539 pounds per square inch, and a temperature of 82°, (*a*) what is its weight? (*b*) what is its weight per cubic foot?

Solution.—(*a*) $W = \frac{P\,V}{.37052\,T} = \frac{17.539 \times 40}{.37052 \times 541} = 3.5$ lb. Ans.

(*b*) $3.5 \div 40 = .0875$ lb. per cu. ft. Ans.

2166. Mixing of Gases.—If two liquids which do not act chemically upon each other are mixed together and allowed to stand, it will be found that after a time the two *acts with the same intensity upon all surfaces in a direction at* ***right angles*** *to those surfaces.*

This law was first discovered by Pascal, and is the most important in hydromechanics. Its meaning should be thoroughly understood.

EXAMPLE.—If the area of the piston *e* in Fig. 729 is 8.25 sq. in., and a force of 150 pounds is applied to it, what forces must be applied to the other pistons to keep the water in equilibrium, assuming that their areas were the same as given before ?

SOLUTION.— $\frac{150}{8.25} = 18.182$ pounds per square inch, nearly.

$$\left.\begin{array}{l} 20 \times 18.182 = 363.64 \text{ lb.} = \text{force to balance } a. \\ 7 \times 18.182 = 127.274 \text{ lb.} = \text{force to balance } b. \\ 1 \times 18.182 = 18.182 \text{ lb.} = \text{force to balance } c. \\ 6 \times 18.182 = 109.092 \text{ lb.} = \text{force to balance } d. \\ 4 \times 18.182 = 72.728 \text{ lb.} = \text{force to balance } f. \end{array}\right\} \text{Ans.}$$

The pressure due to the weight of a liquid may be downwards, upwards, or sideways.

2172. Downward Pressure.—In Fig. 730 the pressure on the bottom of the vessel *a* is, of course, equal to the weight of the water it contains. If the area of the bottom of the vessel *b* and the depth of the liquid contained in it are the same as in the vessel *a*, the pressure on the bottom of *b* will be the same as on the bottom of *a*. Suppose the bottoms of the vessels *a* and *b* are 6 inches square, that the part *c d*, in the vessel *b*, is 2 inches square, and that the vessels are filled with water. The weight of 1 cubic inch of water is $\frac{62.5}{1,728} = .03617$ pound. The number of cubic inches in $a = 6 \times 6 \times 24 = 864$ cubic inches. The weight of the water is $864 \times .03617 = 31.25$ pounds. Hence, the total pressure on the bottom of the vessel *a* is 31.25 pounds, or

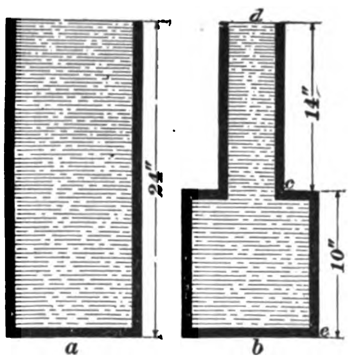


FIG. 730.

0.868 pound per square inch. The pressure in *b*, due to the weight contained in the part *b c*, is $6 \times 6 \times 10 \times .03617 =$ 13.02 pounds. The weight of the part contained in *c d* is $2 \times 2 \times 14 \times .03617 = 2.0255$ pounds, and the weight per square inch of area in *c d* is $\frac{2.0255}{4} = .5064$ pound.

According to Pascal's law, this weight (pressure) is transmitted equally in all directions; therefore, every square inch of the top of the large part of the vessel *b* will be subjected to a pressure of .5064 pound. The area of the part *b c* is $6 \times 6 = 36$ sq. in., and the total pressure due to the weight of the water in the small part will be $.5064 \times 36 = 18.23$ pounds. Hence, the total pressure on the bottom of *b* will be $13.02 + 18.23 = 31.25$ pounds, the same result as in the case of the vessel *a*.

If an additional pressure of 10 pounds per square inch were applied to the upper surface of both vessels, the total pressure on their bottoms would be $31.25 + (6 \times 6 \times 10) =$ $31.25 + 360 = 391.25$ pounds.

If in this case this pressure were obtained by means of a weight placed on a piston, as shown in Figs. 728 and 729, the weight for the vessel *a* would be $6 \times 6 \times 10 = 360$ pounds, and for the vessel *b*, $2 \times 2 \times 10 = 40$ pounds.

2173. The general law for the downward pressure upon the bottom of any vessel:

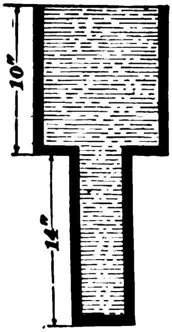


FIG. 731.

The pressure upon the bottom of a vessel containing a fluid is independent of the shape of the vessel, and is equal to the weight of a prism of the fluid whose base is the same as the bottom of the vessel, and whose altitude is the distance between the bottom and the upper surface of the fluid, plus the pressure per unit of area upon the upper surface of the fluid, multiplied by the area of the bottom of the vessel.

Suppose that the vessel *b*, Fig. 730, were inverted, as shown in Fig. 731; the pressure upon the bottom will still be 0.868 pound per square inch, but it will require a weight of 3,490 pounds to be placed upon a piston at the upper surface to make the pressure on the bottom 391.25 pounds, instead of a weight of 40 pounds, as in the other case.

EXAMPLE.—A vessel filled with salt water, having a specific gravity of 1.03, has a circular bottom 13 inches in diameter. The top of the vessel is fitted with a piston 3 inches in diameter, on which is laid a weight of 75 pounds. What is the total pressure on the bottom, if the depth of the water is 18 inches?

SOLUTION.—The weight of 1 cubic inch of the water is $\frac{62.5 \times 1.03}{1,728} =$ .037254 lb. $13 \times 13 \times .7854 \times 18 \times .037254 = 89.01$ pounds = the pressure due to the weight of the water. $\frac{75}{3 \times 3 \times .7854} = 10.61$ pounds per square inch due to the weight on the piston. $13 \times 13 \times .7854 \times 10.61 =$ 1,408.29 pounds.

Total pressure $= 1,408.29 + 89.01 = 1,497.3$ pounds. Ans.

2174. Upward Pressure.—In Fig. 732 is represented a vessel of exactly the same size as that represented in Fig. 731. There is no upward pressure on the surface *c* due to the weight of the water in the large part *c d*, but there is an upward pressure on *c* due to the weight of the water in the small part *b c*. The pressure per square inch due to the weight of the water in *b c* was found to be .5064 pound (see Art. **2172**); the area of the upper surface *c* of the large part *c d* is evidently $(6 \times 6) - (2 \times 2) = 36 - 4 = 32$ sq. in., and the total upward pressure due to the weight of the water is $.5064 \times 32 = 16.2$ pounds.

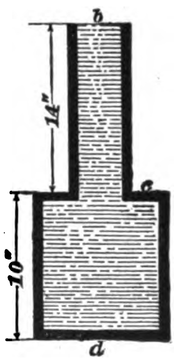


FIG. 732.

If an additional pressure of 10 pounds per square inch were applied to a piston fitting the top of the vessel, the total upward pressure on the surface *c* would be

$$16.2 + (32 \times 10) = 336.2 \text{ pounds.}$$

2175. General law for upward pressure:

The upward pressure on any submerged horizontal surface equals the weight of a prism of the liquid, whose base has an area equal to the area of the submerged surface, and whose

Applications of this principle are seen in the hydraulic machines used for forcing locomotive drivers on their axles, etc., and for testing the strength of boiler-shells.

EXAMPLE.—A suspended vertical cylinder is tested for the tightness of its heads by filling it with water. A pipe whose inside diameter is $\frac{1}{4}$ of an inch, and whose length is 20 feet, is screwed into a hole in the upper head, and then filled with water; what is the pressure per square inch on each head, if the cylinder is 40 inches in diameter and 60 inches long?

SOLUTION.—Area of heads $= 40^2 \times .7854 = 1,256.64$ sq. in.

The pressure per square inch on the bottom head due to the weight of the water in the cylinder $= 1 \times 60 \times .03617 = 2.17$ pounds. $(\frac{1}{4})^2 \times .7854 = .04909$ sq. in., the area of the pipe.

$.04909 \times 20 \times 12 \times .03617 = .426$ pound = the weight of water in pipe = the pressure on a surface area of .04909 sq. in.

The pressure per square inch due to the water in the pipe is $\frac{1}{.04909} \times .426 = 8.68$ pounds per square inch upon the upper head. Ans.

The pressure per square inch on the lower head is $8.68 + 2.17 = 10.85$ pounds. Ans.

EXAMPLE.—In the last example, if the pipe be fitted with a piston weighing $\frac{1}{4}$ of a pound, and a 5-pound weight be laid upon it, what will be the pressure upon the upper head?

SOLUTION.—In addition to the pressure of .426 pound on the area of .04909 sq. in., there is now an additional pressure upon this area of $5 + \frac{1}{4} = 5.25$ pounds, and the total pressure upon this area is $.426 + 5.25 = 5.676$ pounds. Ans.

The pressure per square inch is $\frac{1}{.04909} \times 5.676 = 115.6$ pounds.

BUOYANT EFFECTS OF WATER.

2183. In Fig. 738 is shown a 6-inch cube, entirely submerged in water. The lateral pressures are equal and in opposite directions. The upward pressure $= 6 \times 6 \times 21 \times .03617$; the downward pressure $= 6 \times 6 \times 15 \times .03617$, and the difference $= 6 \times 6 \times 6 \times .03617$ = the volume of the cube in cubic inches $\times$ the weight of 1 cubic inch of water. That is, the upward pressure exceeds the downward pressure by the weight of a volume of water equal to the volume of the body.

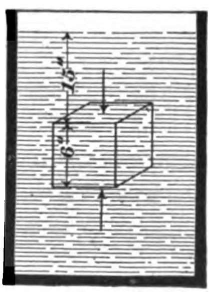


FIG. 738.

facts may be performed as follows: Drop an egg into a glass jar filled with fresh water. The mean density of the egg being a little greater than that of water, it will fall to the bottom of the jar. Now dissolve salt in the water, stirring it so as to mix the fresh and salt water. The salt water will presently become denser than the egg, and the egg will rise. Now, if fresh water be poured in until the egg and water have the same density, the egg will remain stationary in any position that it may be placed below the surface of the water.

HYDROKINETICS.

FLOW OF WATER THROUGH SHORT TUBES.

2185. Hydrokinetics, also called **hydrodynamics** and **hydraulics,** treats of water in motion. The velocity is not the same at all points of the flow, unless all cross-sections of the pipe or canal are equal. That *velocity* which, being *multiplied by the area of the cross-section of the stream*, will equal the total quantity *discharged* is called the **mean velocity.**

Let Q = the quantity which passes any section in one second;
A = the area of the section;
v = the mean velocity in feet per second.

Then, $$Q = A v, \qquad \textbf{(165.)}$$

and $$v = \frac{Q}{A}. \qquad \textbf{(166.)}$$

EXAMPLE.—The area of a certain cross-section of a stream is 27.9 square inches; the velocity of the water through this section is 51 feet per second; what is the quantity discharged in cubic feet?

SOLUTION.—Applying formula **165,** $Q = \frac{27.9}{144} \times 51 = 9.9$ cubic feet per second. Ans.

EXAMPLE.—In the last example, what would the velocity have been to discharge the same quantity had the area of the cross-section been 36 square inches?

SOLUTION.—Applying formula **166**, $V = \frac{9.9}{\frac{36}{144}} = \frac{9.9 \times 144}{36} = 39.6$ ft. per sec. Ans.

2186. Velocity of Efflux.—If a small aperture be made in a vessel containing water, the velocity with which the water issues from the vessel is the same as if it had fallen from the level of the surface to the level of the aperture, all resistances being neglected. This velocity is called the **velocity of efflux.**

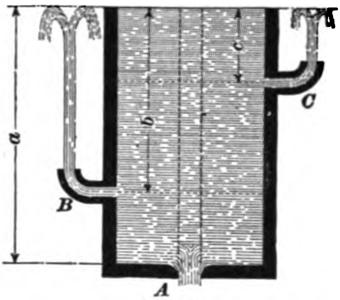


FIG. 740.

The vertical height of the level surface of the water above the center of the aperture is called the **head.** In Fig. 740, a is the head for the aperture A; b is the head for the aperture B; and c is the head for the aperture C.

Let v = the velocity of efflux in feet per second;
h = the head in feet at the aperture considered.

Then, the theoretical velocity of efflux is expressed by the formula

$$v = \sqrt{2gh}. \qquad (167.)$$

Here $g = 32.16$; that is, *the velocity of efflux is the same as if the same weight of water had fallen through a height equal to its head.*

Were it not for the resistance of the air, friction, and the effect of the falling particles, the issuing water would spout to the level of the water in the vessel; that is, to a height equal to its head.

EXAMPLE.—A small orifice is made in a pipe 50 feet below the water-level; what is the velocity of the issuing water?

SOLUTION.—Applying formula **167**, $v = \sqrt{2 \times 32.16 \times 50} = 56.7$ feet per second. Ans.

From the above formula, as in the laws of falling bodies,

$$h = \frac{v^2}{2g}. \qquad (168.)$$

EXAMPLE.—What is the actual velocity of discharge from a small, square-edged orifice in the side of a vessel, if the head is 20 feet?

SOLUTION.—Applying formula **172**,

$v = .98\sqrt{2\,g\,h} = .98\sqrt{2 \times 32.16 \times 20} = 35.15$ feet per second. Ans.

2191. The diameter of the contracted vein at its smallest section is about .8 of the diameter of the orifice, and its area is about $.8 \times .8 = .64$ of the area of the orifice. In Art. **2185**, it was stated that the quantity discharged in cubic feet per second was equal to the area of the section multiplied by the mean velocity, or $Q = A\,v$. This was the theoretical value; *the actual value is the area of the contracted vein multiplied by the actual velocity of efflux*, or $Q = .64\,A \times .98\,v = .627\,A\,v$; that is, the actual discharge is about .627 of the theoretical discharge.

This number, .627, is called the **coefficient of efflux.**

The coefficient of efflux varies somewhat according to the head, and the size and shape of the orifice; but for square-edged orifices, or for orifices in thin plates, its average value may be taken as .615. Hence,

Rule.—*The actual quantity discharged is .615 times the theoretical amount,*

or, $$Q = .615\,A\,v. \quad \textbf{(173.)}$$

EXAMPLE.—The theoretical discharge from a certain vessel is 12.4 cubic feet per minute; what is the amount actually discharged per second?

SOLUTION.— $12.4 \times .615 = 7.626$ cubic feet per minute; $\frac{7.626}{60} =$ .1271 cubic foot per second. Ans.

2192. If the water discharges through a short tube whose length is from $1\frac{1}{2}$ to 3 times the diameter of the orifice (see Fig. 745), the discharge is increased. From a large number of experiments made by different persons, the coefficient of efflux for a short tube may be taken as .815; that is, the actual discharge may be taken

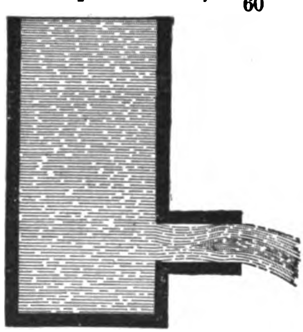


FIG. 745.

2197. In Fig. 748 is represented a weir in which the top of the weir (orifice) is level with the upper surface of the water flowing through it. By means of higher mathematics, it has been found that the *theoretical mean velocity* v_m is equal to $\frac{2}{3}\sqrt{2gh}$.

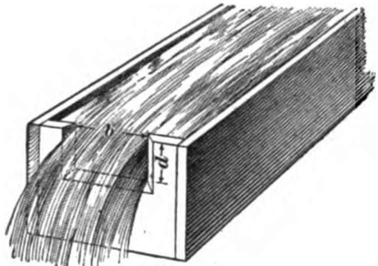


FIG. 748.

2198. If d = the depth of the opening in feet, and b its breadth in feet, the area of the opening $A = d\,b$, and the theoretical discharge is $Q = d\,b\,v_m = \frac{2}{3}\,d\,b\sqrt{2gd}$, the head for this case being taken as d.

The actual discharge is

$$Q_a = .615\,Q = .615\,d\,b \times \frac{2}{3}\sqrt{2gd} = .41\,b\sqrt{2gd^3}. \qquad \textbf{(178.)}$$

That is, *the actual discharge through a weir in cubic feet per second, whose top is on a level with the upper surface of the water, is equal to .41 multiplied by the breadth of the weir, multiplied by the square root of 2 g times the cube of the depth of the weir.* All dimensions are to be taken in feet.

EXAMPLE.—A weir like the one represented in Fig. 748 has a depth d = 18 inches, and a breadth b = 30 inches; what is the actual discharge per minute in cubic feet?

SOLUTION.—Applying formula **178**,

$Q_a = .41 b\sqrt{2gd^3} = .41 \times \frac{30}{12} \times \sqrt{2 \times 32.16 \times (\frac{18}{12})^3} = 15.1$ cubic feet per second.

$15.1 \times 60 = 906$ cubic feet per minute. Ans.

2199. To obtain the mean velocity v_m, divide the actual discharge by the area of the weir.

Thus, $$v_m = \frac{Q_a}{A} = \frac{Q_a}{b\,d}. \qquad \textbf{(179.)}$$

EXAMPLE.—What is the mean velocity in feet per second of the water in the last example?

SOLUTION.—Applying formula **179**,

$$v_m = \frac{Q_a}{b\,d} = \frac{15.1}{2\frac{1}{2} \times 1\frac{1}{2}} = \frac{15.1}{3.75} = 4.027 \text{ feet per second. Ans.}$$

2200. It should be kept in mind that a weir is but a rectangular opening. It is a special name given to a rectangular orifice. Some writers use the term **rectangular notch** instead of weir.

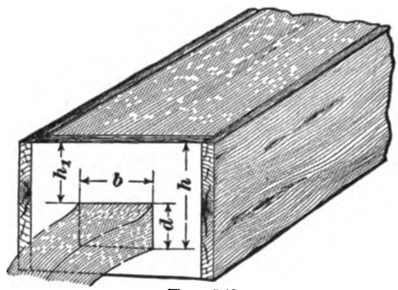


FIG. 749.

2201. In Fig. 749 is represented a weir whose top is below the level of the upper surface of the water. If h_1 is the depth in feet of the top of the weir below the surface of the water, and h is the depth in feet of the bottom of the weir below the surface of the water, the actual discharge Q_a in cubic feet per second is

$$Q_a = .41\, b \sqrt{2g}\left[\sqrt{h^3} - \sqrt{h_1^3}\right]. \qquad \textbf{(180.)}$$

That is, *the actual discharge through a weir, whose top is h_1 feet, and whose bottom is h feet, below the surface of the water, is equal to .41 times the breadth of the weir multiplied by the square root of 2 g times the difference of the square roots of the cubes of the depth of the bottom of the weir, and the depth of the top of the weir.*

EXAMPLE.—A weir like that shown in Fig. 749 has a depth $d = 2$ feet, and a breadth $b = 3$ feet. The depth of the top below the surface of the water is 5 feet; what is the discharge in cubic feet per minute?

SOLUTION.— $h_1 = 5$. $h = 5 + 2 = 7$. Hence, applying formula **180**,

$$Q_a = .41\, b \sqrt{2g}\left[\sqrt{h^3} - \sqrt{h_1^3}\right] =$$

$.41 \times 3 \times \sqrt{2 \times 32.16} \times \left[\sqrt{7^3} - \sqrt{5^3}\right] = 72.41$ cubic feet per second $= 72.41 \times 60 = 4{,}344.6$ cubic feet per minute. Ans.

EXAMPLE.—What is the mean velocity in the last example?

SOLUTION.—Applying formula **179**,

$$v_m = \frac{Q_a}{b\,d} = \frac{72.41}{2 \times 3} = 12.07 \text{ feet per second. Ans.}$$

FLOW OF WATER IN PIPES.

LOSS DUE TO FRICTION.

2202. When water flows from one reservoir to another through a pipe, the velocity of efflux is considerably less than the theoretical velocity due to the head. This loss is

EXAMPLE.—What is the mean velocity of efflux from a 6-inch pipe 5,780 feet long, if the head is 170 feet? Take $f = .021$.

SOLUTION.—Applying formula **181**,

$$v_m = 2.315\sqrt{\frac{h\,d}{f\,l + .125\,d}} = 2.315\sqrt{\frac{170 \times 6}{.021 \times 5{,}780 + (.125 \times 6)}} = 6.69$$

feet per second. Ans.

2204. When the pipe is very long, compared with the diameter, as in the above example, the following formula may be used:

$$v_m = 2.315\sqrt{\frac{h\,d}{f\,l}}, \qquad \textbf{(182.)}$$

in which the letters have the same meaning as in the preceding formula. This formula may be used when the length of the pipe exceeds 10,000 times its diameter.

EXAMPLE.—In the preceding example, calculate the value of v_m by using formula **182.**

SOLUTION.—

$$v_m = 2.315\sqrt{\frac{h\,d}{f\,l}} = 2.315\sqrt{\frac{170 \times 6}{.021 \times 5{,}780}} = 6.71 \text{ feet per second. Ans.}$$

THE ACTUAL HEAD.

2205. The **actual head** necessary to produce a certain velocity v_m may be calculated by the formula

$$h = \frac{f\,l\,v_m^2}{5.36\,d} + .0233\,v_m^2. \qquad \textbf{(183.)}$$

That is, *the total head in feet necessary to produce a velocity of efflux* v_m *in a straight cylindrical pipe is equal to the coefficient of friction multiplied by the length of the pipe in feet, multiplied by the square of the mean velocity of efflux in feet per second, divided by 5.36 times the diameter of the pipe in inches, plus .0233 times the square of the mean velocity.*

EXAMPLE.—A 7-inch pipe 6,000 feet long is required to deliver water with a velocity of 7 feet per second; what must be the necessary head? Assume $f = .026$.

EXAMPLE.—A 5-inch pipe is discharging 360 gallons per minute; what is the mean velocity of efflux?

SOLUTION.— $\frac{360}{60} = 6$ gallons discharged per second. Hence, applying formula **185**,

$$v_m = \frac{24.51 \times Q}{d^2} = \frac{24.51 \times 6}{25} = 5.882 \text{ feet per second. Ans.}$$

2208. If the head, the length of the pipe, and the diameter of the pipe are given, to find the discharge, use the formula

$$Q = .09445\, d^2 \sqrt{\frac{h\,d}{f\,l + .125\,d}}. \qquad \textbf{(186.)}$$

That is, *the discharge in gallons per second equals .09445 times the square of the diameter of the pipe in inches, multiplied by the square root of the head in feet times the diameter of the pipe in inches, divided by the coefficient of friction times the length of the pipe in feet, plus .125 times the diameter of the pipe in inches.*

2209. To find the value of f, calculate v_m by formula **182,** assuming that $f = .025$, and get the final value of f from the following table:

TABLE 45.

$v_m =$	0.1	0.2	0.3	0.4	0.5	0.6
$f =$	.0686	.0527	.0457	.0415	.0387	.0365
$v_m =$	0.7	0.8	0.9	1	$1\frac{1}{4}$	$1\frac{1}{2}$
$f =$	.0349	.0336	.0325	.0315	.0297	.0284
$v_m =$	2	3	4	6	8	12
$f =$	.0265	.0243	.023	.0214	.0205	.0193

EXAMPLE.—The length of a pipe is 6,270 feet, its diameter is 8 inches, and the total head at the point of discharge is 215 feet; how many gallons are discharged per minute?

SOLUTION.—Using formula **182**,

$$v_m = 2.315\sqrt{\frac{h\,d}{f\,l}} = 2.315\sqrt{\frac{215 \times 8}{.025 \times 6{,}270}} = 7.67 \text{ feet per second, nearly.}$$

For $v_m = 6, f = .0214$, and for $v_m = 8, f = .0205$.

$.0214 - .0205 = .0009$ = difference for a difference in the v_m's of 2 ft. per sec.

$.0009 \div 2 = .00045$ = difference for a difference in the v_m's of 1 ft. per sec.

$7.67 - 6 = 1.67$. $.00045 \times 1.67 = .0007515$ = amount to be subtracted from .0214 to obtain f for $v_m = 7.67$. Using but five decimal places, $.0214 - .00075 = .02065 = f$ for $v_m = 7.67$.

Hence, applying formula **186**,

$$Q = .09445\, d^2\sqrt{\frac{h\,d}{f\,l + .125\,d}} = .09445 \times 8^2\sqrt{\frac{215 \times 8}{.02065 \times 6{,}270 + .125 \times 8}} =$$

21.95 gallons per second, nearly.

$21.95 \times 60 = 1{,}317$ gallons per minute. Ans.

2210. If it is desired to find the head necessary to give a discharge of a certain number of gallons per second through a pipe whose length and diameter are known, calculate the mean velocity of efflux by using formula **185.** Find the value of f from Table 45, corresponding to this value of v_m; substitute these values of f and v_m in formula **183,** and calculate the head.

EXAMPLE.—A 4-inch pipe, 2,000 feet long, is to discharge 24,000 gallons of water per hour; what must be the head?

SOLUTION.— $\frac{24{,}000}{60 \times 60} = 6\frac{2}{3}$ gallons per second. Using formula **185**,

$$v_m = \frac{24.51\,Q}{d^2} = \frac{24.51 \times 6\frac{2}{3}}{16} = 10.2 \text{ feet per second.}$$

In Table 45, $f = .0205$ for $v_m = 8$, and .0193 for $v_m = 12$.

$.0205 - .0193 = .0012$ = difference for a difference in the mean velocities of 4 ft. per sec. $.0012 \div 4 = .0003$ = difference for a difference of 1 ft. per sec. $10.2 - 8 = 2.2$. $.0003 \times 2.2 = .00066$. $.0205 - .00066 = .01984$. Then, substituting in formula **183**,

$$h = \frac{f\,l\,v_m^2}{5.36\,d} + .0233\,v_m^2 = \frac{.01984 \times 2{,}000 \times 10.2^2}{5.36 \times 4} + .0233 \times 10.2^2 = 195 \text{ ft.}$$

Ans.

BENDS AND ELBOWS.

2211. In laying pipes, all bends and elbows should be avoided as much as possible. When they are absolutely necessary, they should be as large as the circumstances will effects, not more than 22 feet. This is due to the fact that there is a little air left between the bottom of the piston and the bottom of the cylinder; a little air leaks through the valves, which are not perfectly air-tight, and a pressure is needed to raise the valve against its weight, which, of course, acts downwards. There are many varieties of the suction-pump, differing principally in the valves and piston; but the principle is the same in all.

2213. The Lifting-Pump.—A section of a lifting-pump is shown in Fig. 755. These pumps are used when water is to be raised to greater heights than can be done with the ordinary suction-pump. As will be perceived, it is essentially the same as the pump previously described, except that the spout is fitted with a cock, and has a pipe attached to it, leading to the point of discharge. If it is desired to discharge the water at the spout, the cock may be opened; otherwise, the cock is closed, and the water is lifted by the piston up through the pipe P' to the point of discharge, the valve c preventing it from falling back into the pump, and the valve V preventing the water in the pump from falling back into the well. It is not necessary that there should be a second pipe P', as shown in the figure, for the pipe P may be continued straight upwards.

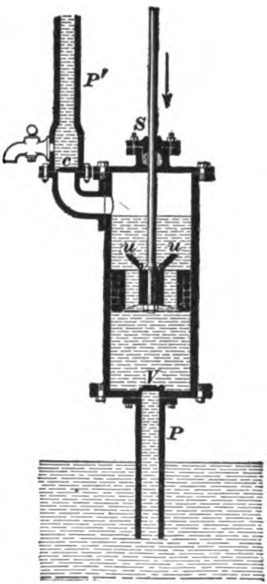


FIG. 755.

In all pumps, the pipe that conducts the water or other liquid to the pump-cylinder is called the **suction-pipe;** the pipe that conducts the water away from the pump-cylinder is called the **delivery** or **discharge pipe.** In Figs. 755 and 756, P is the suction and P' the delivery pipe. The suction-pipe is sometimes called the **inlet-pipe.**

great, and the entire mass must be put in motion during one stroke of the piston.

In order to obtain the advantage of a more continuous discharge, double-acting pumps are used. Fig. 757 shows a part sectional view of such a pump. Two pistons *a* and *b* are used, which are operated by one handle *c*, in the manner

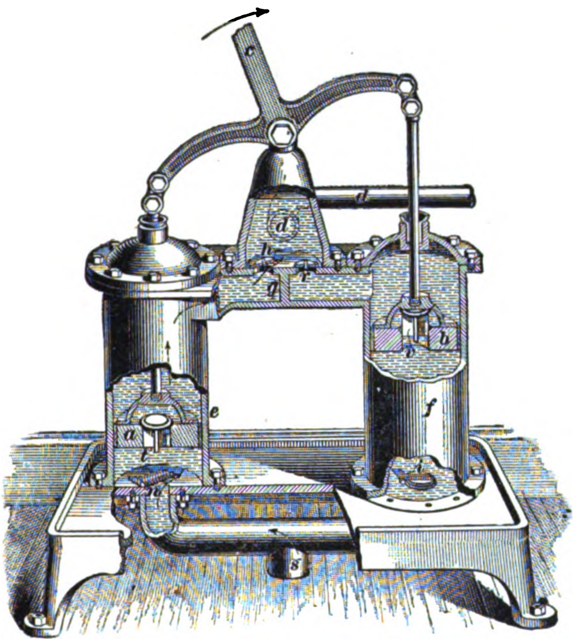


FIG. 757.

shown. The pump has one suction-pipe *s* and one discharge-pipe *d*. The cylinders *e* and *f* are separated by a diaphragm *g*, so that they can not communicate with each other above the pistons. In the figure, the handle *c* is moving to the right, the piston *a* upwards, and the piston *b* downwards. As the piston *a* moves upwards, it lifts the water above it, and causes it to flow through the delivery-valve *h* into the discharge-pipe *d*. This upward movement of the piston creates a partial vacuum below it in the cylinder *e*, and causes the water to rush up the suction-pipe *s* into the cylinder, which prevents the water in the left-hand half from communicating with that in the right-hand half of the cylinder. Suppose the piston to be moving in the direction indicated by the arrow. The volume of the left-hand half of the pump-cylinder will be increased by an amount equal to the area of the circumference of the plunger, multiplied by the length of the stroke, and the volume of the right-hand half of the cylinder will be diminished by a like amount. In consequence of this, a volume of water in the

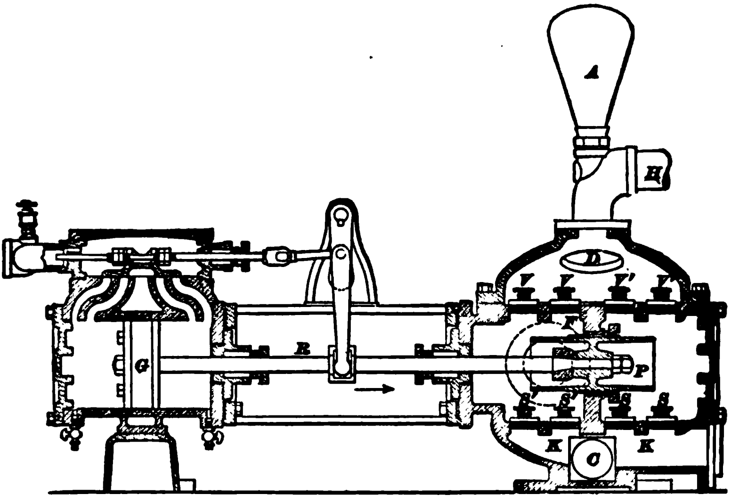


FIG. 758.

right-hand half of the cylinder equal to the volume displaced by the plunger in its forward movement will be forced through the valves *V'*, *V'* into the air-chamber *A*, through the orifice *D*, and then discharged through the delivery-pipe *H*. By reason of the partial vacuum in the left-hand half of the pump-cylinder, owing to this movement of the plunger, the water will be drawn from the reservoir through the suction-pipe *C* into the chamber *K K*, lifting the valves *S'*, *S'*, and filling the space displaced by the plunger. During the return stroke, the water will be drawn through the valves *S*, *S* into the right-hand half of the pump-cylinder, and discharged through the valves *V*, *V* passage and delivery-pipe *D D*. This creates a partial vacuum in the casing and suction-pipe, and causes the water to flow in through *S*. This water is also made to revolve with the vanes, and, of course, with the same velocity. The centrifugal force of the revolving water causes it to fly outwards towards the end of the vanes, and becomes greater the farther away it gets from the center. This causes it to leave the vanes, and, finally, to leave the pump by means of the discharge-passage and delivery-pipe *D D*. The height to which the water can be forced depends upon the velocity of the revolving vanes. In the construction of the centrifugal pump, particular care is exercised in giving the correct form to the vanes; the efficiency of the machine depends greatly upon this point being attended to. What is required is to raise the water; and the energy used to drive the pump should be devoted as far as possible to this one purpose. The water, when it is raised, should be delivered with as little velocity as possible; for any velocity which the water then possesses has been produced at the expense of the energy used to drive the pump. The form of the vanes is such that the velocity with which the water leaves the pump is reduced to an amount just sufficient for its delivery at the proper height.

The number of vanes depends upon the size and capacity of the pump. It will be noticed that in the pump shown in the figure, the vanes have sharp edges near the hub. The object of this is to provide for a free ingress of the water, and also to cut any foreign substance that may enter the pump, and prevent it from working properly.

Centrifugal pumps are sometimes used to raise water 100 feet or more, but they work much more economically for heights of 25 to 40 feet. Almost any liquid can be raised with these pumps; but, when used for pumping chemicals, the casing and vanes are made of materials that the chemicals will not affect.

Mud, gravel, etc., can also be raised when mixed with water, the wear due to these impurities being very slight.

in one stroke is 7.8125 feet. Hence, the number of foot-pounds necessary for one stroke is $681.77 \times 7.8125 = 5,326.33$ foot-pounds. Had this result been obtained by the rule given in Art. **2220,** the process would have been as follows: The weight of the water displaced by the piston in one stroke was found to be 42.61063 pounds. $42.61 \times 125 = 5,326.33$ pounds, which is exactly the same as the result obtained by the previous method, and is a great deal shorter.

EXAMPLE.—What must be the necessary horsepower of a double-acting steam-pump, if the vertical distance between the point of discharge and the point of suction is 96 feet? The diameter of the pump-cylinder is 8 inches; the stroke is 10 inches, and the number of strokes per minute is 120. Add $\frac{1}{3}$ for friction, etc.

SOLUTION.—Since the pump is double-acting, it raises a quantity of water equal to the volume displaced by the plunger at every stroke. The weight of the volume of water displaced in one stroke $= (\frac{8}{12})^2 \times .7854 \times \frac{10}{12} \times 62.5 = 18.18$ lb., nearly.

$18.18 \times 96 \times 120 = 209,433.6$ foot-pounds per minute.

Since $\frac{1}{3}$ is to be added for friction, etc., the actual number of foot-pounds per minute is $209,433.6 + \frac{209,433.6}{3} = 279,244.8$.

One horsepower $= 33,000$ foot-pounds per minute; hence, $\frac{279,244.8}{33,000} = 8.462$ H. P., nearly. Ans.

DUTY OF A PUMP.

2222. *The* **duty** *of any pump or pumping-engine is the number of pounds of water raised one foot high for each 100 pounds of coal burned in the boiler.*

2223. The duty is calculated by multiplying the number of pounds of water discharged in one hour by 100, and by the total height in feet that the water is lifted, and dividing the product by the number of pounds of coal burned during the hour. Since the discharge is usually given in gallons, the following formula may be used, in which

G = number of gallons discharged per hour;

h = total vertical distance in feet between the level of the water in sump, or other source of supply, and the point of discharge;

bottom of the cylinder. The weight of the pump-rods and other moving parts in the shaft, called the **pit-work,** is

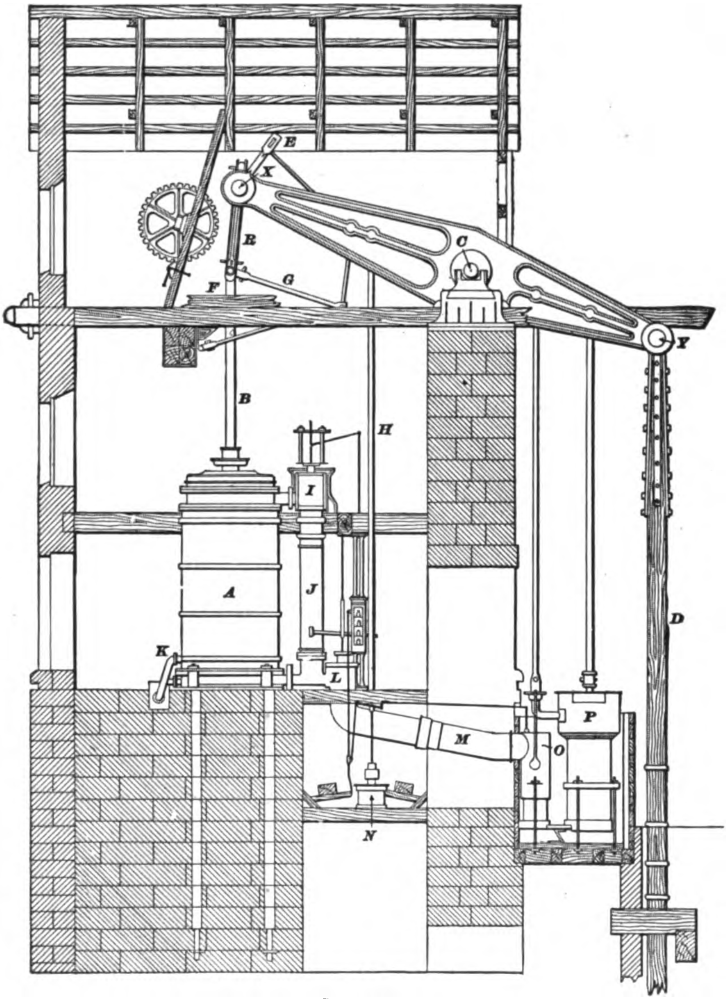


FIG. 760

sufficient to raise the piston to the top of the cylinder when the steam on the upper side of the piston is put in communication with the lower side. The cylinder *A* is steam-jacketed; that is, the cylinder-walls are hollow, and filled than to state their advantages over the plunger-pumps. The pump-rod, being necessarily inside of the delivery-pipe, reduces the effective area of pipe, and increases the friction of the water to some extent, owing to the added surface rubbed against. The rods are concealed, and can not be inspected without removing the entire rod. Not only do the bolts and rods sometimes break, thus rendering their recovery difficult, but the bolts will wear against the stocks, causing loss of power by friction and destroying the pipes.

Lift-pumps are not so liable to sudden injurious strains as the plunger-pumps. They are better adapted for sinking purposes than the plunger-pumps, the impurities in the water being less harmful than in the case of plunger-pumps.

The plunger type of pumps is superior to the lift-pump in nearly every respect for very high lifts, with the accompanying heavy pressure, or when dirty water is being raised. When pumping against a heavy pressure, it is impossible to keep the piston of lift-pumps tight, and prevent the water from leaking. The piston and cylinder of the lift-pump must in every case be a perfect fit, and be truly cylindrical. With plunger-pumps, on the contrary, the rod passes through a stuffing-box, and the plunger may or may not fit the cylinder. When pumping dirty water, the grit comes in contact with the surface that the piston of a lift-pump is constantly traveling over, and destroys both the cylinder and piston very rapidly; whereas, the plunger has to be kept tight at only one permanent place, and the dirt cannot very well get at the surface of the packing on which the plunger or plunger-rod rubs. Every part of a plunger-pump can be readily examined and repaired without taking down the whole apparatus.

PUMP DETAILS.

VALVES.

2233. A section of a pump clack-valve is shown in Fig. 764. *A* and *B* are the clacks, lined with leather on the bottom, to make a tighter fit on the seat, and thus do away with the necessity of grinding the valve when fitting. *C* is back of the valve *A* by means of the stem, and separated by the washers *E*, *E*, *E*. When the water raises the valve, the rings are compressed, and the shock which would be produced by the valve striking the flange is done away with, and with it the liability of breaking the valve. The rings likewise assist in closing the valve. This is called a single-beat valve, because there is but one opening. These valves are used for lifts up to 500 feet.

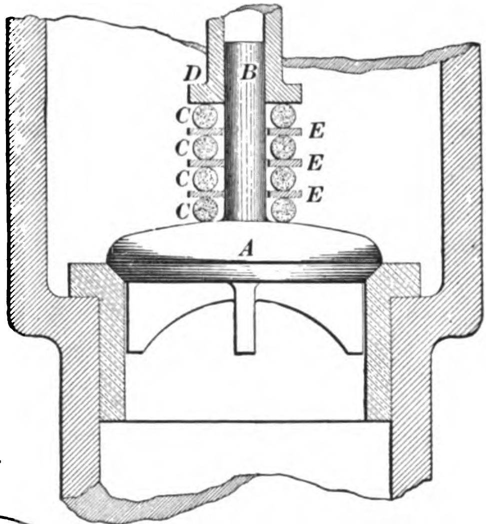


FIG. 765.

2235. For lifts up to 300 feet, India-rubber disk valves give good satisfaction. Fig. 766 shows one of ordinary construction. An India-rubber disk *A* is fixed over the center of the grid *B*. When the water rushes through the holes, the rubber disk is lifted at its ends until it strikes the curved piece *C*, which

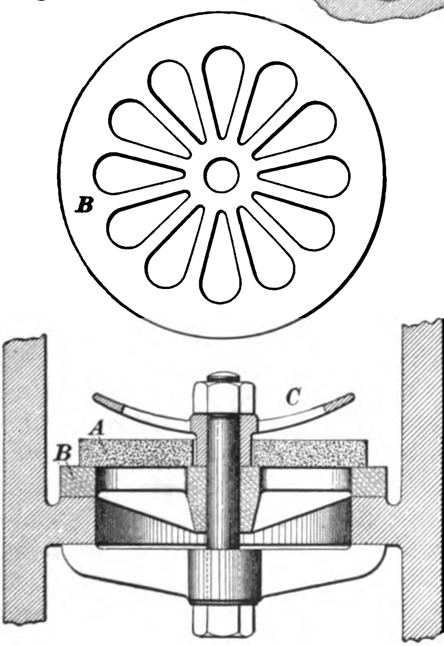


FIG. 766.

is placed there to keep the valve from opening too far. The grid, or seat, *B* is filled with holes, through which the water passes. This valve works well, but is not satisfactory on account of the necessity of constantly renewing it. The valve can not turn, and, therefore, rises and falls back into the same position every time. In consequence of this, the heavy water causes those portions of the rubber disks which cover the holes in the seat to be pressed inwards, and the valves wear out very fast. To obviate this difficulty, the holes in the grid are slanted, as shown in Fig. 767, and a small brass collar is fixed to the center of the disk. The water, rushing in at an angle, rotates the valve slightly each time, thus presenting a new surface to the holes in the seat, and reducing the wear to a minimum. In a later construction of this valve, the grid passages are vertical, as in Fig. 766, but the disk itself has inclined teeth cut in the circumference. This answers the same purpose as the method shown in Fig. 767, and is superior to it, since the direction of the water is not changed by inclined openings.

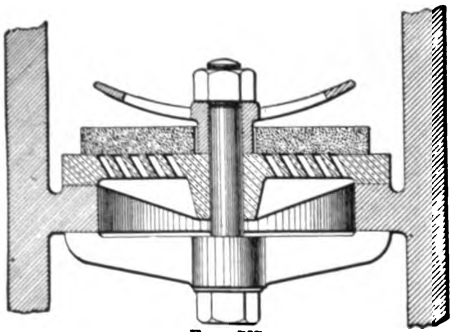


FIG. 767.

2236. A section of a **Cornish double-beat** valve is shown in Fig. 768. This valve is deservedly a favorite, and is used when high pressures are required. Besides being used for a water-valve, it may be used for steam or air. These valves have been applied to pumps working against a head of 700 feet with entirely satisfactory results. They are called double-beat valves because they have two seats and two openings for discharge. *A* is the casing which slides on the vertical stem *B*; when down, it rests on the valve-seats at *C* and *D*. When the pressure below becomes greater than that above, it raises the casing, and the water is discharged through the circular openings at *C* and *D*. The rib around the outside of the casing is for the purpose of strengthening it. The valve-seats are conical. The

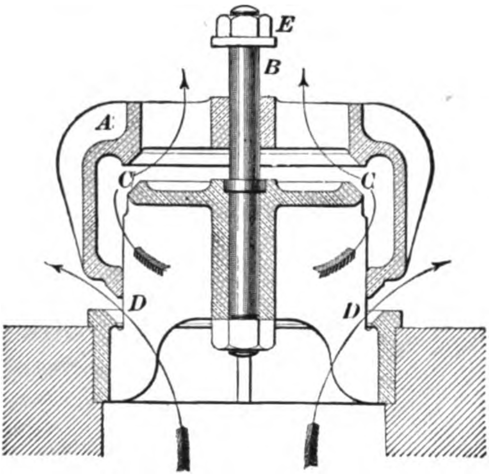


FIG. 768.

figure shows that one opening discharges the water outside of the valve, and the other through the inside. In some cases the valve-seats are flat instead of conical, and have a strip of rubber extending around the entire seat.

PIPES.

2237. The pipes used to convey the water from the mine to the surface are generally made in sections of about ten feet in length, with flanges on each end to bolt them together. The usual practice is to make them of cast iron; when the water is not injurious, however, they are sometimes made of wrought iron, on account of the great reduction in weight; wrought iron being so much stronger than cast iron, the thickness of the pipe may be a great deal less.

A number of different forms of joints are used, one of the best being shown in Fig. 769. The projection *B* (sometimes called a *spigot*) is made just strong enough to prevent its being broken when connecting up the pipes; its

The type of engine employed in this case is a **Corliss-geared engine.** Fig. 779 shows in greater detail an engine of different make, but the same in principle as the one shown in Fig. 778, and which is used for the same purpose. In an arrangement of this kind, it is necessary that the pump-rod should move very slowly while the steam economy is increased by higher speeds. Hence, in Fig. 779, the crank-shaft has keyed to it a stepped pinion, which meshes into a very large stepped gear-wheel. A second crank is keyed to the shaft of the large gear-wheel, and to it is attached one end of a long wooden connecting-rod *T*, whose other end is attached to a bell-crank in a manner shown more clearly in Fig. 778. The second crank thus communicates its motion to the bell-crank *A*, Fig. 778, which in turn operates the pump-rod in the shaft.

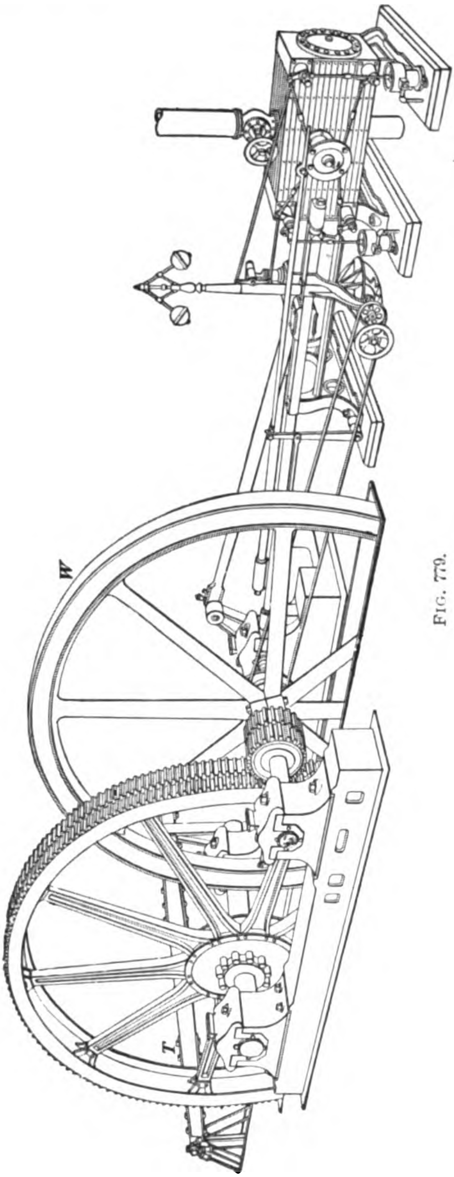


FIG. 779.

BALANCING THE PUMP-RODS.

2247. It has been stated that the water is forced upwards by the weight of the descending pit-work. The weight of the pit-work must then, of course, be greater than the weight of the ascending column of water, and the velocity of the descending pit-work will depend directly on the difference between its weight and the weight of the water-column. There is, however, a practical limit which the speed of the pit-work may not exceed; viz., about 200 feet per minute, or less. One reason for this limit is the liability of the piston to pound the cylinder-head, if moving too fast; and another is that the velocity of the water in the pipe should be not more than 200 to 250 ft. per minute. If, then, the difference between the weight of the pit-work and of the water-column be too large for the required velocity, a balance-bob must be resorted to, as shown in Fig. 778. The pump-rod, in descending, has not only to raise the water-column, but also to lift the weight at the end of the bell-crank. The speed of the descending pit-work can thus be exactly regulated by the weight of the balance.

2248. As an example, suppose the weight of the pit-work is 20 tons, the weight of the water-column raised is 16 tons, and the frictional resistances, say, 3 tons. First find the velocity of the pit-work on the down stroke, and see if the pump-rod needs to be balanced. The total force is 20 tons, and the total resistance is $16 + 3 = 19$ tons, leaving a net force of 1 ton to accelerate the moving mass. The weight to be accelerated is $20 + 16 = 36$ tons; the friction, of course, not requiring acceleration. The formula which expresses the relation between the force, acceleration, and weight, is

$$f = \frac{g\,F}{W}, \qquad \textbf{(188.)}$$

where F is the force; W, the weight; f, the acceleration in feet per second, and g, the acceleration due to gravity, which is usually taken as 32.16 ft. per sec. in a second.

Substituting the values of F, W, and g, in formula **188**,

$$f = \frac{32.16 \times 1}{36} = .89\tfrac{1}{3} \text{ ft. per sec. in a second.}$$

and rods *I*, leaves a vacuum behind it, which is filled by water from the suction-pipe. On the return stroke, the above operations are reversed, *F'* doing the forcing and *F* the suction. It should be understood that the cylinders in which *F* and *F'* work are separated by a partition at *N*, in somewhat the same manner as the two halves of the cylinder

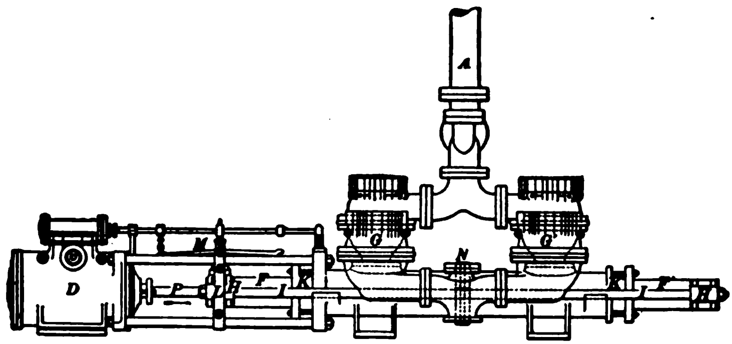


FIG. 781.

in Fig. 758. A detailed description of this arrangement applied to a pump of different manufacture will be described further on.

Two stuffing-boxes, *K* and *K'*, are used to pack the plungers. As will be seen, they are outside of the cylinders, and the bushing can be easily removed, the packing repaired, and the bushing replaced without disturbing the cylinder-head itself in the slightest. The steam-valve is operated in this case by means of the lever *M*, carried to and fro by the upright-piece *L*, which is attached to the piston-rod *P*.

For most purposes, the outside-packed mine-pump is superior to the inside-packed type, but takes up more room.

2253. Fig. 782 shows a **Worthington simple outside-packed duplex mine-pump.** The plunger *A* has nearly completed its stroke in the direction indicated by the arrow, while the plunger *B* has completed the same portion of its stroke in the opposite direction. The steam-valve in the chamber *D* is operated by means of the crank *F*, acting through the long bearing *G*, and actuating the crank *H*, attached to the valve-stem by a link, as shown. The valve in the chamber *E* is actuated in a similar manner by means of the crank *I*. These cranks are so set that the plungers *A* and *B* are always moving in opposite directions. This arrangement, in combination with the air-chamber *L*, produces a nearly uniform discharge. Both pump-cylinders dis-

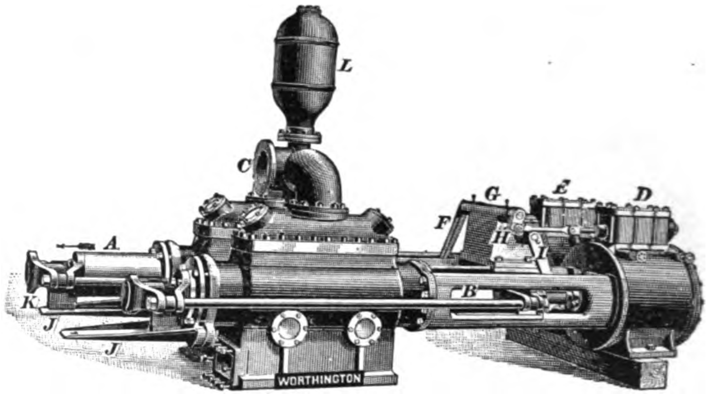


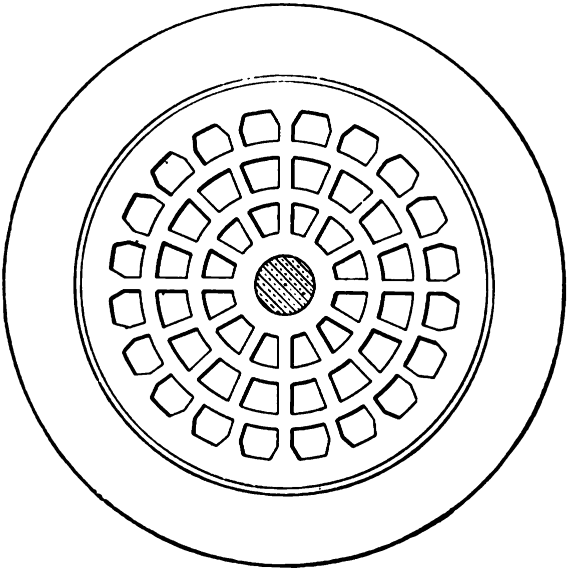
FIG. 782.

charge into the same delivery-pipe *C*. *K* is a *shoe*, one being attached to both ends of both plungers, and moves on the slide *J* at the left, and on the cross-head slide at the right. They prevent the ends of the plungers from falling downwards out of line when near the end of the stroke. The shoes are adjustable for wear. The ends of the plungers are connected by means of yokes and rods in a manner similar to the pump last described. As will be seen, it is outside-packed.

The chief disadvantage of this valve-driving arrangement is that one pump can not be disconnected from the other when the work would require only one pump to be in use. In order that one pump may run, the other must also be in motion.

2254. In Fig. 783 is shown a perspective view of a **Jeanesville compound outside-packed duplex mine-pump.** This is a very powerful pump, the one illustrated having the following dimensions:

2257. A section through two of the discharge-valves is shown in Fig. 784. In order to more clearly show the working of these valves, an enlarged view is given in Fig.



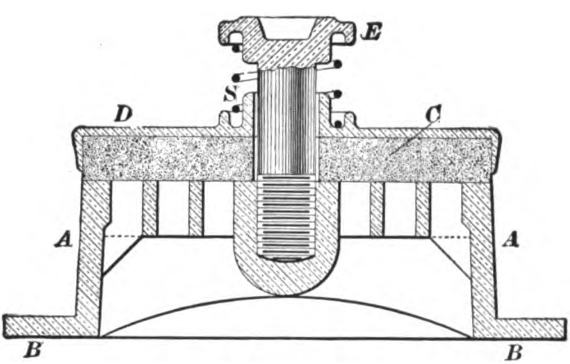


FIG. 785.

785. The valve-seat A is held in place by means of the flange B (see also Fig. 784). As shown in the top view, the valve-seat is perforated by a large number of small holes; this is necessary, since the valve C is made of rubber. The

is discharged through a pipe bolted to the flange *H*. *F* is the pipe which leads the cold water to the condensing-chamber *E*. *G* is the air-pump for removing the condensed water and discharging it either into the boiler, if placed near the pump, or into the sump. *I* is a pipe through which the exhaust steam from the air-pump passes to the condenser.

These pumps are intended for very heavy duty, the one shown in the cut being designed for a discharge of 1,000 gallons per minute under a head of 800 feet. They will pump water vertically 1,000 feet or over on single lifts.

SINKING-PUMPS.

2259. When putting down a new shaft or deepening an old one, the so-called **sinking-pump** is used to drain the water from the shaft-bottom, so that the work may proceed. These pumps must necessarily be portable, and are suspended by a chain attached to eye-bolts in the pump. They are also provided with wrought-iron clamps, by means of which they may be attached to the timbers in the shaft when it is desired to fix them in position temporarily. Hence, as the shaft gets deeper, the chain may be lengthened out, an extra joint placed on the upper end of the delivery-pipe, and it is again ready for business. The sinking-pump is subjected to the hardest usage of any other mine machine. The water pumped is invariably gritty and often acid. The water trickling down on the pump from above carries mud along with it, and so completely covers the pump that it is hardly distinguishable at times from the soil itself. Notwithstanding all this, a sinking-pump must work night and day, often up to the limit of its capacity, and its failure, even for a day, at a critical period, may flood a shaft, which would require a week or more to recover.

2260. In Fig. 787 is illustrated two views of a **Cameron sinking-pump.** This pump meets all of the conditions required of a sinking-pump, and is a favorite with mine operators. There is no outside valve mechanism whatever, and nothing short of actual breakage of the pump diaphragm to separate the two plunger-cylinders, as in the pump illustrated in Fig. 784, two stuffing-boxes are placed in the center to accomplish the same purpose. This device is frequently used in ordinary horizontal mine-pumps, and when so used the pumps are called **center-packed,** to distinguish them from the **inside-packed** and **outside-packed pumps.** The center-packed pump is considered superior to the inside-packed pump for mining purposes, but not to be so convenient as the outside-packed pump. The center-packed sinking-pump, however, is considered superior to the other two. The action of this pump is as follows:

G is the suction-pipe and *H* the delivery-pipe. Suppose the plunger to be moving in the direction indicated by the arrow. The water is forced out of the chamber *L*, which communicates with the delivery-pipe *H* by means of the valve *C*, and lifts *C*, thus flowing into *H*. As the plunger moves down it leaves a vacuum behind it; the water in the shaft rushes up the suction-pipe, raises the valve *D*, and fills the upper part of the plunger-cylinder. When the stroke is reversed, the valves *C* and *D* close, and the valves *E* and *B* open, the water being forced up the pipe *H*, through the valve *E*, and the chamber *L* is filled through the opening of the valve *B*. *F* is, of course, the air-chamber. The section shown by the view on the right is taken in a rather peculiar manner, the greater part being taken through the center line of the engine, so as to show the plunger, stuffing-boxes, etc., and the part showing the valves being taken on the center line of the valves *E* and *D* of the view on the left.

It is quite customary to use a sinking-pump to raise the water from the sump to the first station, since the sinking-pump may be raised or lowered according to the depth of the water in the sump. A single steam-pipe down the shaft supplies both the sinking-pump and the main pump. When used for this purpose, the sinking-pump exhausts into the sump.

On account of its portability, the sinking-pump is especially adapted to the recovery of flooded mines.

close to the pump suction-pipe *G*. *H* is a steam-trap for the purpose of removing entrained water and water of condensation from the steam before entering the pump. *I* is the delivery-pipe which connects directly with the column-pipe *O* (main delivery-pipe) in the shaft *L*. *N* is a float

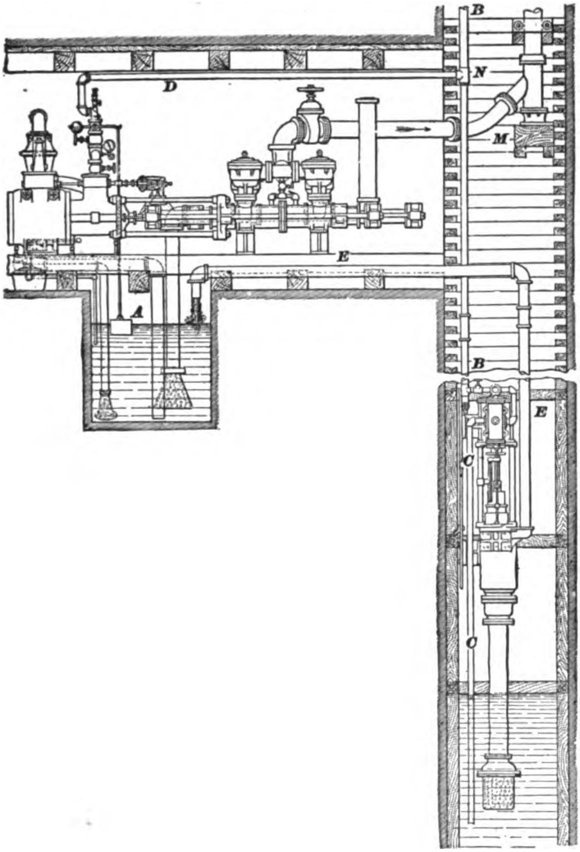


FIG. 789.

which rises and lowers as the level of the water in *A* rises and lowers. This action operates a balanced throttle-valve *P* on the steam supply-pipe. Should the water in the sump become too low, the float falls so far that the engine stops automatically. The movement of the float up or down also

The steam-pipe is connected at *E* and the suction-pipe at *S*. *C* is an air-chamber, which has no connection with *B* and *A*, but communicates with the suction-pipe by means of the opening *I*, situated below the suction-valves *F* and *G*. The two latter valves are made of flat rubber, and are held to their seats, as shown in the cut, by means of the spindles *R* and *T*. The spindles are raised and lowered, as the case may require, by means of the nuts *f* and *e*. *H*, *H* are plates which may be removed to facilitate the examination of the valves. *D* is a hard-rubber ball, which acts as a valve for admitting the steam to the chambers *A* and *B*. *M* and *N* are exhaust-valves, also made of rubber, and situated in the chamber *L*, attached to the other half of the cylinder. They are raised and lowered in the same manner as the suction-valves, by turning the nuts *g* and *h*. *K* is the delivery or column pipe.

2264. The action of the pulsometer is as follows: Both chambers, *A* and *B*, are filled with water to about the height of the water in *B*, Fig. 791. The valve *d* is then opened, and the steam enters one of the two chambers *A* and *B*. Suppose it enters *B*, the valve *D* being at the right, as shown. The water in *B* will be forced through the delivery-valve *N* into and up the column-pipe *K*. This will continue until the water-level gets below the edge of the discharge-opening *P*. At this point the steam and water mix in the discharge-passage, and the steam is condensed, creating a vacuum in *B*. The pressure in *A* is now greater than in *B*, owing to the vacuum in *B*, and the ball-valve *D* is shifted to the left, the steam entering the chamber *A*, and driving the water through *M* into the passage *O* and column-pipe *K* in the manner just described. While this is being done, the pressure of the atmosphere forces the water up the suction-pipe *S*, opening the suction-valve *F*, and into the chamber *B*, filling it. When the suction-valve is closed, owing to the reshifting of the ball-valve *D* to the other side, the suction-water enters the air-chamber *C* through the inlet *I*, and is brought gradually to rest by the a little air to the cylinder. The incoming water compresses this air, and soon closes the valve. When the air has been compressed to such an extent as to balance the outside pressure of the atmosphere, the suction-valve *G* will close, and no more water can get in. Since the same thing occurs in the other chamber, it is evident that the amount of air admitted controls the amount of water admitted during the suction period, more water entering when there is less air in the chamber, and *vice versa*. The admission of the air is controlled by turning the valves *a* and *b*, and these can be so adjusted that the suction-valve in either chamber will close at the instant the ball is shifted to the other side, admitting the steam.

Moreover, the air prevents the steam from coming in contact with the water during the forcing process, until the water-level has sunk below the edge of the discharge-orifice. Air being a poor conductor of heat, the steam does not condense until the mixture of the steam and water has taken place.

2266. The pulsometer will raise water by suction to a height of about 26 feet, although it is not advisable to exceed 20 feet, and force it, when necessary, to a height of 100 feet. It has no wearing parts whatever except the valves, which are easily and cheaply repaired. It will work in almost any position, and, when once started, requires no further attention. There are no parts which can get out of order. It will pump anything, including mud, gravel, etc., that can get past the valves. Its first cost is low, and it requires no foundations to set up. There is no exhaust-steam to make trouble, and no noise. It uses more steam than a pump, its duty being from 7,000,000 to 10,000,000 foot-pounds per 100 pounds of coal. One of the leading pump manufacturers of this country states that the *average* duty of single steams is from 15,000,000 to 20,000,000; of compound pumps about 30,000,000, and of compound condensing-pumps about 50,000,000 foot-pounds per 100 pounds of coal burned.

ELECTRIC PUMPS.

2267. All of the pumps heretofore described for underground mine work have been steam-pumps. The simple pump, both single and duplex, can be run by means of compressed air. As mentioned before, there are several ways by which the pumps may be driven other than by the use of steam. Of late, the electric pump is being used to some extent, and will, perhaps, in time, displace steam-pumps for underground mine use.

2268. A cut of an electric pump is shown in Fig. 792. It is what is termed a **triplex pump;** that is, there are three cylinders side by side, all three being operated at the same time from the same shaft *A*. *B* is the motor, the electric current being conveyed to it by two wires from a dynamo at the surface. As the motor revolves, it turns with it the shaft to which is keyed the pinion *C*. *C* gearing with *D* causes *D* to turn the pinion *E*, keyed to the same shaft as *D*. *E* gearing with *F* revolves the crank-shaft *A*, and with it the cranks *G*, *H*, and *I*, which impart a reciprocating motion to their plungers *L*, *K*, and *J*. These cranks are set at angles of 120° with each other, and the plunger-cylinders all discharge into the same delivery-pipe *M*, the consequence being that a nearly uniform discharge is secured, much better than that attained in the duplex construction, which is itself superior, in this respect, to the single pump. *N* is the suction-pipe. These pumps are made to raise water in single lifts from 400 to 800 feet, and to deliver at the point of discharge from 50 to 450 gallons per minute, according to size. In combination with these pumps, a small pump, called the **tail-pump,** is generally used to deliver the suction water to the main pump under a slight pressure, thus insuring the plunger-cylinder being full before the commencement of the return stroke.

The pump illustrated is termed a **horizontal triplex electric pump.** In many cases they are made vertical; that is, the plungers move vertically instead of horizontally. They are also made both triplex and duplex; the latter quently, also the crank-shaft *A*, is revolving once. Therefore, if the crank-shaft *A* makes 50 revolutions per minute, the motor will make $50 \times 10\frac{1}{2} = 525$ revolutions per minute.

2269. Fig. 793 shows a **duplex electric sinking-pump.** *E* and *F* are the two plunger-rods, the plungers themselves being central-packed, as shown at *H*; *D* is the clamping-piece for attaching the pump to the shaft-timbers, and *G* the eye-bolt for suspending it from a chain. *A* is the discharge-pipe; *B*, the suction-pipe, and *C*, the air-chamber. The only visible moving parts are short portions of the plungers and rods at *H* and *E*. No damage whatever can come to this pump from the water. It will work just as well under water as out of it. The only objection on this score that can be urged against it is, that the wires which conduct the electricity to it may be broken by the falling debris. If proper care be exercised, this should not happen. They will raise water vertically 200 feet, and discharge from 100 to 300 gallons per minute, according to size.

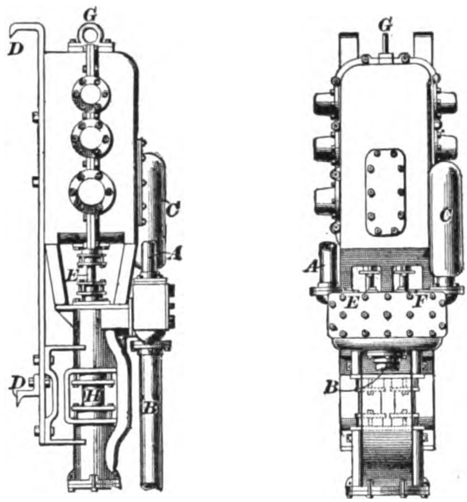


FIG. 793.

2270. A cut of a **water-power electric pumping-plant** is given in Fig. 794. *A* is a sinking-pump, which raises the water from the lowest level to the first station, discharging through the pipe *C* into the tank *B*. From this station, the water is raised to the next higher one by means of, in this case, **a vertical triplex pump,** and so on by one or more lifts to the surface. The wires which conduct the electricity down the shaft are enclosed in a small iron pipe suction-valves. Suppose the piston, valves, etc., to be in the position shown. The water which drives the engine fills the chest *D*, and has the full pressure due to its head; it passes through the port *a* into the space *I*; there is also a communication with the main valve-chamber *J* from which the water passes through the port *b* into the cylinder, and drives the piston in the direction of the arrow. Attached to the piston-rod is an arm *L*. When the piston nears the end of its stroke to the right, the arm *L* strikes the lug *M*, and causes the rod *N* to actuate the lever *O*, one end of the lever being attached to the rod *N*, and the other end to the valve-stem *S*, by the link *Q*. The valve *B*, pressed equally by the water on both ends, is caused to be moved to the left, opening the port *e*. The water in the chest *D* then enters the space *K*, and causes the valve *C* to be moved to the left, forcing the water confined in the space *I* through the port *a* and the under side of the valve *B* into the pipe which conducts away from the pump the water discharged through the exhaust-port *d*. To better understand this last statement, suppose the piston to be at the end of its stroke to the left, and that the arm *L*, striking the lug *M*, has shifted the valve *B* to the right, as shown in the cut. The valve *C* will also move to the right, for the reasons before given, and the water in the space *K* will be forced through the port *e* and under the valve into the water exhaust-pipe.

2273. In the case of hydraulic-engine pumps, the motor-piston *P* is always smaller than the pump-piston, but the length of stroke of both pistons is the same. If there were no friction or other resistance than that due to the weight of the water, the areas of the two pistons would be inversely proportional to the heads acting upon the pistons; that is, if a be the area of the motor-piston (*P* in Fig. 795), A the area of the pump-piston, h the head which acts upon the pump-piston, and h_1 the head against which the pump works (height of lift), the following proportion expresses the relation between them:

$$a : A :: h_1 : h.$$

The amount which the pump will be required to discharge is usually known; also the heads h and h_1. The discharge being known, the length of the stroke and area of pump-piston can be so taken that the volume displaced by the piston in one stroke, multiplied by the number of required strokes per minute, shall be equal to the required discharge. When this has been done, the values of A, h_1, and h will be known, and a can be found from the proportion just given.

EXAMPLE.—Suppose that the head of water which acts upon the motor-piston is 640 feet, and the pump is required to discharge 80 gallons of water per minute under a head of 120 feet, what are the diameters of the motor and pump pistons, the length of their strokes, and the number of strokes per minute?

SOLUTION.—Since one cubic foot of water contains 7.48 gallons, the number of cubic feet in 80 gallons would be $\frac{80}{7.48} = 10.695$ cu. ft. For a pump of this kind, it would be well not to have the piston speed exceed 80 feet per minute. Assume the number of strokes per minute to be 60, then the amount of water displaced in one stroke is $10.695 \div 60 = .17825$ cu. ft. $= .17825 \times 1{,}728 = 308$ cu. in. If the stroke be taken as 10 in. long, the area of the pump-piston will be $308 \div 10 = 30.8$ sq. in., and the diameter will be $\sqrt{\frac{30.8}{.7854}} = 6\frac{1}{4}$ in., nearly. Ans.

The piston speed will evidently be $\frac{60 \times 10}{12} = 50$ feet per minute. As this is well within the limit advised (80 feet per minute), it may be used, and, in case the pump should be required to deliver more than 80 gallons per minute at any time, the speed can be increased to meet the demand. To find the diameter of the motor-piston, first find the area by the proportion given above. In this case, $h = 640$, $h_1 = 120$, and $A = 30.8$; hence,

$$a : 30.8 :: 120 : 640, \text{ or } a = \frac{30.8 \times 120}{640} = 5.775 \text{ sq. in.}$$

The diameter, consequently, equals $\sqrt{\frac{5.775}{.7854}} = 2\frac{3}{4}$ in., nearly. Ans.

The values just calculated are theoretical values; the friction of the water in the pipes and the leakage past the piston will modify the results to a considerable extent; consequently, when calculating the sizes of a hydraulic pumping-engine, employ the method given in the latter part of this section, using formulas **190** to **196**.

In this arrangement, the water used in the motor-cylinder has to be raised again to the point where the pump discharges, and from there to the surface.

2274. Fig. 796 shows a hydraulic engine operated in a different manner, which is said to give excellent results, and may be worked as easily under water as out of it, should the mine be flooded. The motor-cylinder does not discharge the water remaining in the cylinder after the stroke is completed, into the sump, as described in the last figure, but uses the water over again, as the following description will show: *A* is a steam-engine, whose piston-rod *T* passes through the steam-cylinder *Q*, and also through two single-acting pump-cylinders *I* and *R*. The hydraulic engine is located at the bottom of the mine; it consists of two single-acting motor-cylinders *F* and *G*, and two single-acting pump-cylinders *H* and *S*. A small pipe *D* connects the pump-cylinder *I* with the motor-cylinder *G*, and another pipe *E*, of exactly the same size, connects the pump-cylinder *R* with the motor-cylinder *F*. *B* is a tank which contains sufficient water to charge the pipes *D* and *E*. *J* is the suction-pipe which conducts the water to the pump, and *K* is the column-pipe which delivers it to the surface.

2275. The action of the apparatus is as follows: Suppose that the pipes *D* and *E* are empty. The cock *U* is opened, and the water flows from the tank *B* until the pipes *D* and *E* are filled. The cock *U* is then closed, and the engine started. Let the engine be moving in the direction indicated by the arrow on the fly-wheel; the pistons in the cylinders *Q*, *I*, and *R* will then be moved towards the left. The piston in the cylinder *I* will force the water in *I* through the pipe *D* into the cylinder *G*. The piston in *G* is connected with the pistons in *S*, *H*, and *F* by means of the long piston-rod *W*. The pressure of the entering water against the piston in *G* forces it and the other three pistons in *S*, *H*, and *F* to the left. This action forces the water in the cylinder *H* through the discharge-valve *P* into the column-pipe *K*, causing it to discharge at *Y*. The vacuum

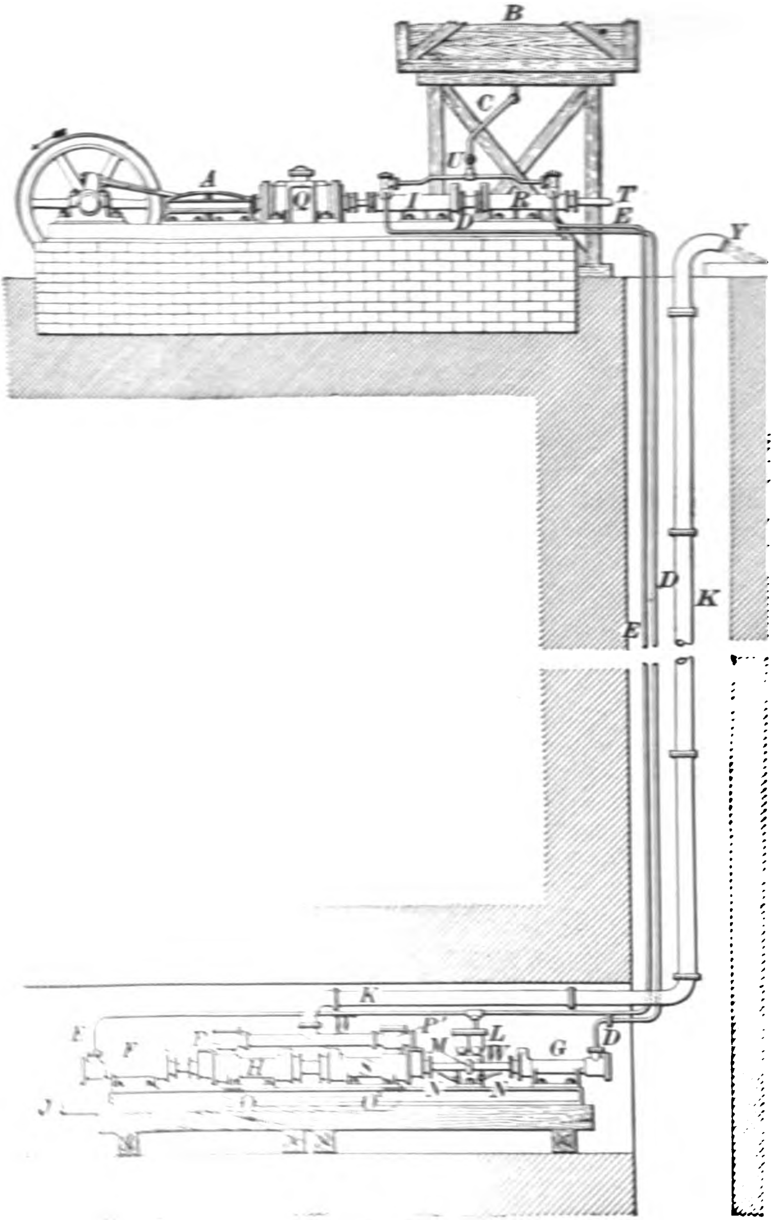


FIG. [illegible]

created in *S* by this movement of the piston in *S* to the left causes the water to enter the suction-pipe *J*, and flow through the suction-valve *O'* into the cylinder *S*. The water in front of the piston in the cylinder *F* is forced out through the pipe *E* into the cylinder *R*, to fill the vacuum created in *R* owing to the movement of the pistons to the left. When the stroke of the engine is changed to the right, all of these various movements are reversed. The water is forced out of the cylinder *R*, through the pipe *E*, into the cylinder *F*, thus forcing the pistons in *H*, *S*, and *G* to the right. The water is then drawn through *J* into *H*, and forced out of *S* into *K*, the water in *G* being forced out of *G* through *D* into *I*.

When the pipes *D* and *E* have once been filled, there will be no necessity of replenishing them with water, except to make up the loss occasioned by evaporation or leakage at the joints and past the pistons. In order to guard against any harm resulting from this leakage, and thus having more water in one of the pipes than in the other, relief-valves are situated at *L*; these valves are operated by the levers *N*, *N*, which are themselves operated by the lug *M*, on the piston-rod striking the end of one of them and forcing it downwards, opening one of the two valves, and allowing the two pipes *D* and *E* to communicate with each other, thus equalizing the pressure of the water on both sides of the piston in one of the motor-cylinders and stopping it. The piston-rod *T* projects through the cylinder *R*, in order that there shall not be more water on one side of the piston in *R* than on the other side. The piston speed of the pumps in this arrangement should not exceed 80 feet per minute, nor the speed in the pipes *D* and *E* 300 feet per minute. For this reason, the engine must run very slowly, or else must be geared so that the speed of the pistons shall not exceed 80 feet per minute. It will, of course, be understood from the above description that the water in the pipes *D* and *E* merely conveys the force exerted by the steam-engine piston in *Q* to the pump-cylinders *H* and *S*. This method of conveying the power of the steam to the pumps is much cation between the siphon and the chamber. All four valves, *A*, *B*, *D*, and *L*, are operated by handles, as shown. In order to keep the air from getting past the valve *L* when it is closed, thus entering the pipe and destroying the action of the siphon, the chamber *K* is kept filled with water. The lever *F* has fastened to its short arm a rod *G*. Attached to this rod are the handles of the valves *B* and *D*, and to its lower end the weight *I*. When in the position shown, the valve *B* is open and *D* is closed. In order to start the siphon, the valve *A* is closed and *L* is opened. The lever *F* is then pulled down. This action raises the handles of the valves *D* and *B* to the position shown by the dotted lines, opening the valve *D* and closing the valve *B*. The water flows into the siphon from the column-pipe through the small pipe *C*. When the siphon is filled, the water appears at chamber *K*, the valve *L* is closed, the lever *F* is released, and the weight *I* pulls it back into the position shown in the cut, closing the valve *D* and opening the valve *B*. The valve *A* is then opened, and the siphon is in working condition.

2284. In order that a siphon shall work properly, it is necessary that air should be kept out of the pipe, or, if it gets in, means should be provided for its escape. Air will enter the

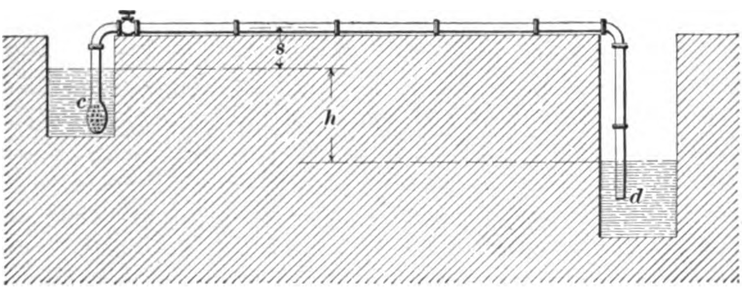


FIG. 800.

pipe in spite of all precautions, and, when once in, will collect at the highest point of the siphon because the pressure there is least. The joints must be perfectly air-tight; even then the water absorbs air, which is given out again as the also true of a siphon having a double bend, as shown in Fig. 802. Here the air will collect at *E* and *F*—at *E* first,

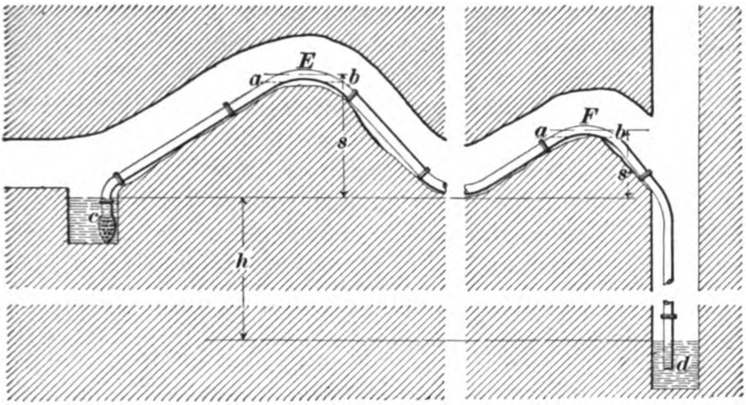


FIG. 802.

and *F* afterwards. This is an extremely bad construction, and should in all cases be avoided.

2286. A device which will remedy the bad action of a siphon to a considerable extent, by removing the air, is shown in Fig. 803. Here *A* is an air-tight vessel connected

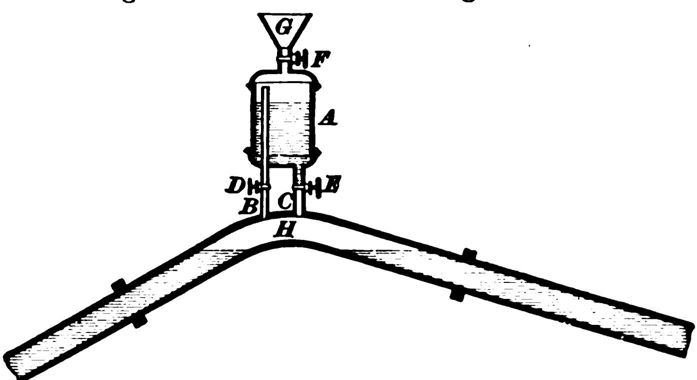


FIG. 803.

with the siphon by two pipes, *B* and *C*. The pipe *B* extends to very nearly the top of *A*, while the pipe *C* barely enters the bottom. Each pipe has a valve, *D* and *E*. On the top head is the vertical distance in feet between the level of the water at suction and the level of the water at discharge. If the discharge-end is not submerged, the head will be the vertical distance between the level of the water at the suction and the end of the discharge-pipe. It makes no difference how far below the water the ends of the siphon may extend. The two ends of the siphon may, in fact, be level. The head is measured as described, and the direction of the flow will always be from the higher to the lower *water-level.* The length of the pipe is, in all cases, measured from *c* around to *d.*

EXAMPLE.—A siphon has a total length of 1,420 feet; its diameter is 4 inches, and the distance between the water-levels is 38 feet. What is the discharge in gallons per hour?

SOLUTION.—It is first necessary to find the velocity by formula **182.**

Thus, $v_m = 2.315\sqrt{\frac{hd}{fl}} = 2.315\sqrt{\frac{38 \times 4}{.025 \times 1,420}} = 4.79$ ft. per sec.

From Table 45, $f = .023$ for $v_m = 4$, and .0214 for $v_m = 6$; difference $= .023 - .0214 = .0016$ for a difference of 2 feet per second in the velocity $= .0016 \div 2 = .0008$ for a difference of 1 foot per second in the velocity. $4.79 - 4 = .79$. $.0008 \times .79 = .000632$ = amount to be subtracted from .023 to give the value of f for $v_m = 4.79$. Hence, $f = .023 - .0006 = .0224$, using but four decimal places. Substituting the values of f, l, h, and d in formula **186,**

$$Q = .09445\,d^2\sqrt{\frac{hd}{fl + .125\,d}} = .09445 \times 4^2\sqrt{\frac{38 \times 4}{.0224 \times 1,420 + .125 \times 4}} =$$

3.2778 gal. per sec. $= 3.2778 \times 60 \times 60 = 11,800$ gal. per hour, very nearly. Ans.

CALCULATIONS PERTAINING TO PUMPS.

2289. To find the pressure in pounds per square inch corresponding to any given head of water:

Rule.—*Multiply the head in feet by .434; the result is the pressure in pounds per square inch.*

2290. To find the head of water corresponding to a given pressure in pounds per square inch:

Rule.—*Multiply the given pressure in pounds per square inch by 2.304; the result is the head in feet.*

Example.—What pressure will a head of 120 feet of water exert?

Solution.—Applying the first rule,

$$120 \times .434 = 52.08 \text{ lb. per sq. in. Ans.}$$

Example.—What head of water will exert a pressure of 65 lb. per sq. in.?

Solution.—Applying the second rule,

$$65 \times 2.304 = 149.76 \text{ feet. Ans.}$$

2291. To find the size of the plunger-cylinder to discharge a given number of gallons per minute:

Let G = number of gallons discharged per minute;
S = plunger speed in feet per minute;
d = diameter of cylinder in inches.

Then,
$$d = 4.95\sqrt{\frac{G}{S}}.$$

Since, however, there is always more or less slip of the water past the plungers, it is usual to add $\frac{1}{4}$ of the required number of gallons to the value given to G in the above formula, to allow for this slip. Doing so, the formula becomes

$$d = 5.535\sqrt{\frac{G}{S}}. \qquad \textbf{(190.)}$$

Formula **190** should always be used when calculating the size of the plunger-cylinder to discharge a certain number of gallons per minute. The piston speed is the number of feet traveled per minute by the plunger when forcing water; that is, it equals the length of the stroke in feet multiplied by the number of working strokes per minute. If the pump is double-acting, the number of working strokes is the same as the total number of plunger-strokes, both forward and back; if single-acting, half of that number.

Example.—What should be the diameter of a pump-plunger required to discharge 130 gallons of water per minute, the speed of the plunger to be 115 feet per minute? If the pump is double-acting and the stroke is two times the diameter, how many strokes must it make per minute, and what is the length of the stroke?

SOLUTION.—Applying formula **190**,

$$d = 5.535\sqrt{\frac{G}{S}} = 5.535\sqrt{\frac{130}{115}} = 5.88 \text{ in., say, } 5\tfrac{7}{8} \text{ in. Ans.}$$

Since the stroke is twice the diameter,

$$\text{stroke} = 5\tfrac{7}{8} \times 2 = 11\tfrac{3}{4} \text{ in.} = \frac{11.75}{12} \text{ ft. Ans.}$$

$$\text{Number of strokes} = 115 \div \frac{11.75}{12} = \frac{115 \times 12}{11.75} =$$

117.44 strokes per minute, nearly. Ans.

This speed is rather high for a pump, and should be employed only when absolutely necessary.

2292. To find the approximate discharge in gallons per minute of a mine-pump, when the diameter and plunger speed are known, use the following formula:

$$G = .03264\, d^2 S. \qquad \textbf{(191.)}$$

The same allowance has been made for the slip in this formula that was made in formula **190.** If the theoretic discharge is required, $G = .0408\, d^2 S$.

EXAMPLE.—What is the probable discharge of a duplex double-acting mine-pump whose plungers are 10 inches in diameter, stroke 24 inches, and which makes 40 strokes per minute?

SOLUTION.—Applying formula **191**,

$G = .03264\, d^2 S = .03264 \times 10^2 \times (2 \times 40) = 261.12$ gal. per min., since 24 in. = 2 ft. and the piston speed $= 2 \times 40$ ft. per min. The total discharge is twice this amount, or

$$261.12 \times 2 = 522.24 \text{ gal. per min. Ans.}$$

EXAMPLE.—In the above example, what is the theoretic discharge?

SOLUTION.— $G = .0408\, d^2 S = .0408 \times 10^2 \times (2 \times 40) = 326.4$ gal. per min. $326.4 \times 2 = 652.8$ gal. per min. Ans.

2293. To find the horsepower of a steam or air cylinder to discharge a certain number of gallons of water per minute with a given lift, substitute in the following formula, in which H = the number of horsepower, h = vertical height in feet between the highest point of the center of the delivery or column pipe and the level of the water in the sump or place from which it was taken, and G = the number of gallons discharged per minute:

$$H = .00038\, G\, h. \qquad \textbf{(192.)}$$

The diameter of the steam-cylinder is found by formula **194.**

$$D = 205\sqrt{\frac{292.6}{71 \times 120}} = 38 \text{ in., very nearly.}$$

Diameter of suction-pipe, $d_1 = .35\sqrt{G} = .35\sqrt{770} = 9.712$ in., say 10 in.

Diameter of delivery-pipe, $d_2 = .25\sqrt{770} = 6.937$ in., say 7 in.

Hence,			
	Diameter of plunger,	14 in.	Ans.
	Diameter of steam-cylinder,	38 in.	
	Diameter of suction-pipe,	10 in.	
	Diameter of discharge-pipe,	7 in.	
	Stroke of pump,	42 in.	
	Number of strokes per minute,	$34\frac{2}{7}$.	
	Horsepower,	292.6.	

EXAMPLE.—Find the sizes of a duplex pump to fulfil the same conditions given in the last example, assuming the stroke to be about $2\frac{1}{2}$ times the diameter of the plunger, and the steam-pressure to be 76 pounds per square inch.

SOLUTION.—The total horsepower and the diameter of the discharge-pipe (common to both) will be the same as before. Each pump-cylinder will discharge $\frac{770}{2} = 385$ gallons per minute.

Hence, applying formula **190,**

$$d = 5.535\sqrt{\frac{385}{120}} = 10 \text{ in., very nearly.}$$

Stroke $= 10 \times 2\frac{1}{2} = 25$ in., say 24 in., or 2 ft.

The number of strokes per minute $= 120 \div 2 = 60$.

Horsepower of each steam-cylinder $= \frac{292.6}{2} = 146.3$.

Applying formula **194,**

$D = 205\sqrt{\frac{146.3}{76 \times 120}} = 25.9$ in., the diameter of the steam-cylinder, say 26 in.

The suction-pipes each deliver 385 gallons per minute to the pump; hence, applying formula **195,**

$$d_1 = .35\sqrt{385} = 6.87 \text{ in., say 7 in.}$$

Consequently,			
	Diameter of plungers (2),	10 in.	Ans.
	Diameter of steam-cylinders (2),	26 in.	
	Diameter of suction-pipes (2),	7 in.	
	Diameter of discharge-pipe (1),	7 in.	
	Stroke of pump,	24 in.	
	Number of strokes per minute,	60.	
	Horsepower of each cylinder,	146.3.	
	Total horsepower,	292.6.	

2297. Starting a Pump.—See that the pump is well oiled, and that all pipes and connections are free from obstructions; see that the stuffing-boxes and plungers are properly packed. Open the charging and relief pipes, to fill the suction and cylinders with water and drive out the air; also, open the drain-cocks of the steam-cylinder. Before starting, allow the steam-cylinder to warm up thoroughly. Turn on the steam gradually, and run the pump at slow speed for a short time.

Failure of a pump may be due to a multiplicity of causes, the chief of which are the following: Air in the pump-chamber or in the suction-pipe; dirt in the suction-pipe or in the valves; suction-pipe too long or too small and crooked; air-chamber too small; leaky steam-valves or warm pistons or plunger; pump hot and filled with vapor; improper design of pump for the work to be done.

The greatest difficulty met with in pumping mine-water is the chemical action of the water upon the pump-cylinders, plungers, rods, valves, etc. It is particularly destructive in the anthracite coal regions. Portions of old mine-pumps are seen in which some of the cast-iron parts were so soft that they could be easily cut with a knife. They have the appearance of a honeycomb. Other instances have been frequently noted where the water has dripped on a steel rail from the roof of a mine, and eaten a hole through it. When the mine-water is in this condition, the life of a pump is short at the best. The exposed cast-iron parts are made of the hardest cast iron that can be worked. The water will attack wrought iron and steel even quicker than cast iron. This chemical action is much less rapid on gun-metal, phosphor-bronze, and several other alloys; hence, in well-constructed pumps for raising acid water of this kind, the valves are made of this material when not made of rubber. In cases of this kind, and also when the water is very gritty, the cylinders are bored larger than the plunger, and a gun-metal or phosphor-bronze shell, about an inch thick, is inserted. The wear comes principally on the bottom, and when it has worn more than desired there, the shell can be turned partly around, so that the wear may come at another point. When worn out, the plunger and shell can be replaced, and the old shell melted up.

F. II.—47

(719) Give the rule for determining the amount of displacement of a fault.

(720) (*a*) What are fossils? (*b*) How can a knowledge of them be obtained?

(721) (*a*) What class of rocks is thickest in the Appalachian coal field? (*b*) What class of rocks is thickest in the western coal fields of North America?

(722) Are the anthracite and bituminous coals of Pennsylvania the same deposit? Answer fully.

(723) In what epoch did the trilobites shown as Nos. 9 and 10, Fig. 374, exist?

(724) What is the name given to designate the eroded crest of an anticlinal axis?

(725) Is coal ever found below igneous rock? Can you give an instance?

(726) In what age did insects first appear?

(727) What would be the probable temperature of strata, in degrees Fahrenheit, at a depth of 900 feet?

(728) (*a*) Name the two modes of determining and limiting eras, ages, periods, etc. (*b*) Name the five grand divisions in geology, not by their names, but by what their names signify.

(729) (*a*) Name the North American coal fields that belong to the Carboniferous Age. (*b*) Which are productive?

(730) Which is the great limestone period in the Devonian Age in America?

(731) (*a*) To what epoch does the mountain limestone belong? (*b*) To what epoch does the millstone grit belong?

(732) (*a*) In what respect does the Permian differ from the Carboniferous Proper? (*b*) Does it contain coal?

(733) Is a stratum formed during the same period, shale in one place and limestone at another a short distance away? Answer fully.

(734) What is a dyke?

(735) Do anticlinals always form the higher ground?

(771) Are there any coking coals in the Laramie-Cretaceous formations?

(772) Do igneous rocks ever contain fossils? Answer fully.

(773) (*a*) Sketch a synclinal. (*b*) Can a synclinal be directly under an anticlinal? Answer fully.

(774) Are any metamorphic rocks found in the Cretaceous formations?

the line *1* to *2* be prolonged to find the coal at the same depth as in *No. 3*? (*d*) What is the exact dip of the seam? (*e*) Make a drawing to a scale of 300 feet = 1 inch, and show the direction of the dip and also of the strike.

Ans. { (*a*) 233⅓ ft. (*b*) 500 ft. (*c*) 281.25 ft (*d*) 1 in 16.63.

(782) What is meant by triangulation?

(783) What is meant by the calorific power of coal, and upon what constituent does this power depend?

(784) How would you take a sample from a seam of coal that would fairly represent its value?

(785) Explain the nature of rocks which are black in color.

(786) Upon what does the breadth of a coal terrace depend?

(787) A piece of coal weighs 530 grains in air and 105 grains in water; what is its specific gravity?

(788) If in Fig. 405, Art. **1429,** the seam *A A* dips due east at an angle of 46° 20′, and the bore hole *E* is 550 feet from the outcrop, at what depth will this bore hole cut the seam *A A*?

(789) What points should be considered before a tract of land is extensively prospected?

(790) Mention some cases where the condition of the outcrop of a coal seam can give a wrong idea of its true nature.

(791) How would you reduce the size of a sample from a seam of coal in order to obtain a small quantity for analysis?

(792) What indications of the presence of minerals can be found in streams, and what do these indications show?

(793) In what cases is it unprofitable to work a seam of good coal?

(794) Is it ever necessary to sink a number of shafts to properly work a coal seam? If so, explain the conditions.

(795) What is the rule for the position of the beds when the seams dip with or away from the slope of the valley ?

(796) Show by a sketch and explain how you would endeavor to find the outcrop of a coal seam by means of prospect trenches.

(797) What are the limiting angles of intersection of sight lines in triangulation ? Show their size by sketches and explain the sketches.

(798) What are dip and strike faults ?

(799) What is a coking coal, and upon what does this property depend ?

(800) Show by sketch and explain the influence of slip of blossom on thickness of coal seam.

(801) What is the nature of the first examination that a prospector should give a new region ?

(802) If prospect trenches show encouraging yet not sufficient indications, how may the search be continued ?

(803) Explain what is shown by horizontal and by vertical sections.

(804) How is the outcrop of a seam marked on a plan ?

(805) What topographical features are sometimes indications of the presence of coal seams ?

(806) What is the form of the timber used for cribbing girths, and what is the distance between sets ?

(807) The specific gravity of a 4½-foot seam of coal is 1.4; what is the tonnage per acre ? Solve in two ways.

(808) What considerations govern the adoption of the scale to which a preliminary survey should be drawn ?

(809) What is meant by coal blossom ?

(810) In what cases are mines opened by drifts and when by slopes ?

(811) Explain how a spring of water can be due to a fault.

(812) Under what circumstances should a coal field be opened by a shaft, and in what part of the field should the shaft be sunk ?

SHAFTS, SLOPES, AND DRIFTS.

(813) Upon what does the method of opening out a coal field depend?

(814) Where would you place the shaft in opening out a coal field in which the seam has an inclination of from 3 degrees to 5 degrees, and considerable water is expected? State your reasons.

(815) State the different ways of opening out a seam of coal, pitching from 45 degrees to 50 degrees, and outcropping well up the mountain side. Also, state which method you believe to be the best under the conditions mentioned.

(816) What are the different forms of shafts, and which is the most prevalent in America?

(817) Explain how the exact location of a shaft is definitely fixed.

(818) Over what part of a shaft is the temporary hoisting frame erected, and why so placed?

(819) To what depth is the walling or timbering carried in a shaft?

(820) Under what conditions are the outside timbers removed as the walling is built up?

(821) Where should a wedging curb be located in strata producing a great deal of water?

(822) Why is a shaft sunk below the coal seam?

(823) Explain the use of supporting curbs.

(824) What is the best kind of bricks for shaft lining?

erately inclined seam by means of a water-level drift or tunnel?

(842) Give the general points which determine the location of a shaft.

(843) What should be the thickness of cast-iron tubbing in a shaft 15 feet in diameter and at a point 375 feet below the surface?

(844) How is the water which percolates through the solid strata of a shaft carried off?

(845) How are the guides arranged for the bucket while sinking a shaft?

(846) What are the various materials of which shaft walling is made?

(847) Explain the methods of plumbing a shaft.

(848) In what three ways can quicksand be consolidated sufficiently strong to be excavated by the pick and shovel?

(849) When are diamond or percussion drills used to advantage in sinking shafts?

(850) What is meant by sumping holes?

(851) How would you tamp a hole charged with dynamite in order to get the best results?

(852) Explain the proper methods of thawing dynamite cartridges.

(853) Aside from tamping the hole properly, what is done to secure the best results when several cartridges are placed in the hole?

(854) What objections are there to fuse blasting?

(855) Under what conditions is the churn drill an effective means of boring?

(856) Describe the method of using the hammer and jumper.

(857) Explain the difference in the methods of exploding black powder and dynamite.

(858) How does ignition take place when an electric current is used in blasting?

(859) When should an extra strong exploder be used, and why?

(860) What precaution should be taken while placing a detonator within the cartridge?

(861) What is meant by firing (1) in series? (2) in parallel? (3) in multiple series?

(862) What method of piling would you use to sink through 40 feet of quicksand near the surface?

(863) What is the drum method of sinking?

(864) Describe the Gobert process of sinking through quicksand, using your own language.

(865) What form of piling would you use to sink through a thick bed of quicksand struck some distance below the surface?

(866) Explain Triger's method of sinking.

(367) What difficulties are encountered by sinking by the drum method?

(868) Why is the bottom part of the trepan used in the Lippman method of sinking bifurcated?

(869) What difficulty is there in sinking by the "long hole" method?

(870) Explain fully, and in your own language, the best method of sinking a shaft through hard rock containing water under great pressure.

(871) What advantages are gained by leaving the water in the shaft while sinking by the Kind-Chaudron process?

(872) Explain the process of deepening a shaft where hoisting goes on incessantly.

(873) Describe the method of deepening a shaft where one compartment can be used for hoisting the loose material.

(874) Where should the widening of a shaft be commenced, and what does the process necessitate?

(875) Give the different kinds of guides used in a shaft.

(876) How are the round iron and wire rope guides kept taut?

(877) What is a slope?

(878) What determines the position of the first set of timbers while sinking a slope?

(879) When is piling used in sinking a slope?

(880) What determines the size of a slope?

(881) How are the timbers set with reference to the pitch of the slope?

(882) What should be the batter of a set of slope timbers, and what precautions should be taken in making the joints?

(883) How is the track in a slope kept from slipping down the pitch?

(884) State the form of arch that should be used in a slope where great pressure is expected from all directions.

(885) Explain how the face of a wet slope in a thick seam is arranged and advanced.

(886) What is a drift?

(887) How far below a coal seam dipping inwards 0° 30′ should a drift in which it is desirous to have a grade of $1\frac{1}{2}$ per cent. in favor of the loaded cars be started, the horizontal distance from the drift mouth to the parting to be 200 yards?

Ans. 14.238 feet.

(888) The following data are known: Anticipated depth of shaft, 600 feet; desired tonnage, 1,200 tons per day of 8 hours; inside depth of car, 3 feet; average width of car, 4 feet, and top width, 5 feet; output speed, 36,000 feet per hour. What should be the dimensions of a rectangular shaft of two hoisting compartments and a pumpway 6 feet wide, allowing 1 foot between the side of the car and the buntons, which are 10 inches wide, for clearance, guides, etc., and assuming the broken coal to weigh 50 pounds per cubic foot?

Ans. { 21 ft. 8 in. long. 9 ft. 4 in. wide.

METHODS OF WORKING COAL MINES.

(PART 1.)

(889) What determines the size of shaft pillars?

(890) What should be the general guide in any district in fixing the size of slope or shaft pillars?

(891) A shaft 625 feet deep is surrounded on all sides by buildings, the furthest one from the shaft being 125 feet distant. What should be the size of the shaft pillar?

(892) Why is draw more likely to affect the alinement of a shaft than that of a slope?

(893) Why should slope pillars increase in width as the slope advances downwards?

(894) What conditions of top and bottom require the largest pillars?

(895) State why squeezes frequently occur in slopes.

(896) Where two contiguous seams, separated by 20 or 30 yards of strata, are worked together by the pillar and chamber method, what should be the relative position of the pillars in the two seams?

(897) How should shafts and slopes be sunk with respect to the dip?

(898) Describe the general features of the arrangements of landings, turnouts, and pit bottoms, in cases where arching is unnecessary.

(899) What should be the minimum size of slope pillars?

(900) What per cent. grade is used on landings?

(901) State in what direction, relative to the dip, pillars should be formed to be strongest.

(902) Why is pillar drawing delayed where the coal is soft?

(903) What must be carefully considered before the drawing of pillars is begun?

(904) Define (*a*) creep, (*b*) thrust.

(905) How would you stop a creep where it is gradually coming upon a section of the mine?

(906) What considerations are made in determining the size of pillars in the main workings?

(907) What conditions fix the size of the pillars relative to the breasts or rooms?

(908) When are rooms turned off both butt entries, and when are they turned off but one of the pair of butt entries?

(909) Which case in the last question requires the least amount of entry-driving?

(910) By what method would you work a 6-foot seam of coal which is 800 feet deep, has a soft bottom, gives off considerable gas, and readily disintegrates under atmospheric agencies? Give your reasons.

(911) What are barrier pillars?

(912) How is the track arranged in a breast pitching from 10° to 18°?

(913) At what pitches is sheet iron laid in the breasts of an anthracite seam?

(914) Describe two methods of constructing manways up the sides of the breasts.

(915) What is meant by "working on battery"?

(916) State the advantages of drawing off the surplus coal in a breast by a center chute.

(917) Why are the gangways in thick, pitching seams sometimes driven near the roof?

(918) In pitching seams, what danger is there in turning off the rooms the full width from the heading or airway?

(919) How is this risk avoided?

(920) When the chutes leading to the breasts pass under

the airway, what is done to restore ventilation to the rest of the breasts in case the manway is closed by a cave-in ?

(921) What are check batteries ?

(922) What is "rock-chute mining," and what are the undetermined points in connection with it ?

(923) Explain how several contiguous seams can be worked by tunneling horizontally through the intervening strata.

(924) What is a "back breast," and what does it accomplish ?

(925) Explain a method of robbing or drawing pillars in thick, pitching, anthracite seams.

(926) In approaching abandoned workings supposed to be filled with gas or water, what precautionary measures are necessary ?

(927) What determines whether or not twin seams should be worked separately ?

(928) Why are chutes not more frequently used in bituminous mines ?

(929) Explain fully how you would open up a breast in a seam 30 feet thick, of a soft, gaseous nature, and having a pitch of 60°.

(930) What direction should the productive entries have in general, with respect to the face cleats, and why ?

(931) How would you set a post in a seam pitching 36° ? Give the principle involved.

(932) When is it advisable to set props with their thick ends up ?

(933) How is mopping of props prevented when the bottom heaves ?

(934) What is done to cause uniformity of weight upon the props ?

(935) How are short curves and crooks avoided in driving headings ?

(952) When a slope has a very steep pitch, how is the coal hoisted?

(953) What disadvantage is likely to occur when caging is done from both sides of the shaft?

(954) What limits the use of iron plates in the operation of caging?

(955) If a heading is driven on the strike of the seam towards abandoned workings filled with water and located about 20 feet on the pitch, above the approaching heading, how should bore-holes be driven?

(956) What should be the minimum thickness of a barrier pillar between two anthracite collieries, when the seam is 15 feet thick and the workings are 400 feet vertically below the drainage level?

(957) What should be the minimum thickness of a barrier pillar between two bituminous mines when the seam is 6 feet thick, of average hardness, and the workings are 300 feet vertically below the drainage level?

(958) Describe the method of constructing a timber dam to divert the flow of water under small heads.

(959) What, according to formula, should be the thickness of a cylindrical wooden dam with a radius of curvature of 30 feet, to resist a maximum water head of 200 feet?

Ans. 7 ft.

(960) According to formula what should be the thickness of a cylindrical brick dam to close an opening 7 feet high, after trimming, and to resist a maximum water-head of 250 feet? Ans. 9 ft.

(961) What should be the thickness of a spherical brick dam to close an opening 8 feet high and 8 feet wide, after trimming, to resist a maximum water-head of 300 feet?

Ans. 6 ft. 4 in.

(962) What is the use of puddled clay in the construction of dams?

(963) What should be used as mortar in the construction of brick or masonry dams?

(976) Where should the mining or bearing in be done in a seam of coal, and what should be the dimensions of the same?

(977) What danger is there in attempting to support too great a width of roof along the working face?

(978) Where the line of working face has considerable pitch, how is the face proportioned for the convenience of the miners?

(979) How are levels and temporary haulways laid out?

(980) How is the coal taken to the roadheads where the mine car is not taken along the working face?

(981) Where is a weak roof most likely to break, and how can it be prevented from breaking in that particular place?

(982) When the roof has a tendency to slip down hill, what points must be considered in order that the packwalls will not be destroyed?

(983) When is it necessary to consider the strata above that immediately overlying the coal?

(984) What determines the distance between the working face and the gob?

(985) How are pillars or chocks constructed in pitching seams?

(986) What determines the distance between levels which cut off the roadways leading to the working face?

(987) What is the principal point considered by miners while working a longwall face?

(988) Upon what does the degree to which the coal will be fractured along the working face depend?

(989) How is a skilful miner able to produce more lump coal than an unskilful one?

(990) How are the steps arranged at the face where pairs of roads are used for inclines?

(991) What is done where thick seams are worked by longwall?

(992) Where is the shearing usually made?

(993) When the roadways leading to the face are on the full rise, how is the coal delivered to the levels?

(994) Where the seam is pitching, how is the weight on the high side packwalls made to act vertically or nearly so?

(995) In what direction should the working face advance relative to the cleats, in order to obtain coal at a minimum cost?

(996) What in longwall takes the place of powder in loosening the coal?

(997) From what sources is material for stowage and packwalls obtained?

(998) What are the objections to stepped faces?

(999) What order is maintained in setting props along the working face?

(1000) Why is it necessary to take a certain portion of coal from the low side of a level and then tightly pack the space thus made?

(1001) What effect has gas on the working of coal?

(1002) Give the principal difficulties encountered in working pitching seams by longwall.

(1003) What points must be carefully considered while working contiguous seams?

(1004) What is the principal object in removing the chocks and props from the gob?

(1005) What is the direction of the face cleats with reference to the line of maximum dip?

(1006) What special advantages are there in favor of "longwall retreating" where conditions are such that "longwall advancing" can be used?

(1007) Upon what does the amount of settlement of the roof depend?

(1008) Explain how you would work three contiguous seams separated one from the other by from 4 to 6 feet of

(1026) When are permanent doors put in, and what is previously done to direct the air to the face?

(1027) When is a slight heaving of the bottom at the face an advantage?

(1028) When props can not be recovered with safety for use again, how should they be destroyed?

(1029) What advantage is gained by combining longwall advancing and longwall retreating?

(1030) How may a great deal of the preliminary or narrow work in longwall retreating be delayed until considerable working face is formed?

(1031) In what case does timber drawing require special care?

(1032) Which system of working coal mines affords the best conditions for ventilation, and why?

(1033) If no building is more than 96 feet from the center of a shaft whose circular pillar is found to be 135 yards in diameter, what is the probable depth of the shaft?

Ans. 426 feet.

shaft, and the weight of the rim is 13,000 pounds, what is its kinetic energy when making 150 R. P. M.?

Ans. 1,883,661.7 ft.-lb.

(1055) What should be the width of a single leather belt to transmit $2\frac{1}{2}$ horsepower when the belt has a velocity of 2,000 feet per minute? The diameter of the smaller pulley is 14 inches, and the belt has 18 inches of its length in contact with it. Ans. $1\frac{1}{8}$ inch.

(1056) (*a*) What is meant by inertia? (*b*) by weight? (*c*) How is weight measured?

(1057) The speed of a certain belt is 3,000 feet per minute; if it drives a 48-inch pulley, how long will it take the pulley to make 100 revolutions? Ans. 25.13 sec., nearly.

(1058) Find the point of suspension of a rectangular cast-iron lever 4 feet 6 inches long, 2 inches deep, and $\frac{3}{4}$ inch thick, having weights 47 and 71 pounds hung from each end, in order that there may be equilibrium. Take the weight of a cubic inch of cast iron as .261 pound.

Ans. { Short arm = 22.342 in.
Long arm = 31.658 in.

(1059) When two pulleys are used to transmit power, which is called the driven and which the driver?

(1060) The driver is 2 feet in diameter and the driven is 32 inches in diameter; if the driven makes 63 R. P. M., how many R. P. M. must the driver make? Ans. 84 R. P. M.

(1061) A certain gear has a pitch of $1\frac{1}{8}$ inches, and its pitch diameter is 11.48 inches; how many teeth has the gear? Ans. 32 teeth.

(1062) A fly-ball governor is designed to run at 88 R. P. M. The speed of the engine is 200 R. P. M. The diameter of the governor-pulley is 8 inches; the number of teeth in the bevel-gear which it turns, 44, and the number of teeth in the other bevel-gear, 75. What must be the diameter of the pulley on the crank-shaft which drives the governor-belt? Ans. 6 in.

(1063) A bookbinder has a press, the screw of which has

(1101) A velocity of 30 miles per hour corresponds to how many feet per second? Ans. 44 ft. per sec.

(1102) The stroke of a steam-engine is 28 inches, and it makes 1,500 strokes in 6 minutes; what is the velocity of the piston in feet per second? Ans. $9\frac{13}{18}$ ft. per sec.

(1103) State Newton's three laws of motion.

(1104) A pulley on the main shaft is 40 inches in diameter, and makes 120 R. P. M. What must be the diameter of a pulley on the countershaft that is to make 160 R. P. M.?
Ans. 30 in.

(1105) (*a*) What is a rack? (*b*) a worm-wheel? (*c*) a worm?

(1106) (*a*) What distinguishes epicycloidal teeth from the involute teeth? (*b*) Name two advantages which the latter possess over the former.

(1107) An inclined plane has a length of 1,200 feet and a height of 125 feet. It is required to pull a load of 50,000 pounds up this plane. A block and tackle having 6 fixed and 6 movable pulleys is stationed at the top of the plane, and the weight end of the rope is attached to the load. If the rope which connects the block to the load is parallel to the plane, what force will it be necessary to exert on the free end of the rope to pull up the load, no allowance being made for friction? Ans. 434 lb.

(1108) (*a*) What do you understand by centrifugal force? (*b*) by centripetal force?

(1109) Define (*a*) work; (*b*) horsepower; (*c*) kinetic energy; (*d*) potential energy.

(1110) Two pulleys have diameters of 8 inches and 20 inches; the distance between their centers being 19 ft. 3 inches, what must be the length of a belt to drive them?
Ans. 42 ft. $3\frac{1}{2}$ in.

(1111) Two bodies, starting from the same point, move in opposite directions, one at the rate of 11 feet per second and the other 15 miles per hour. (*a*) What will be the distance per min.? The diameter of the smaller pulley is 15 inches, and the length of the arc of contact is 21 inches.

Ans. 11.4 H. P., nearly.

(1122) It is required to raise a weight of 18,000 pounds by means of a screw having 3 threads per inch; if the length of the handle is 15 inches, and there is a loss of 10,000 pounds, due to friction, etc., what force will it be necessary to apply to the handle? Ans. 99 lb., nearly.

(1123) The fly-wheel of an engine is 9 feet in diameter (outside); if the fly-wheel makes 100 R. P. M., how many miles will a point on the rim travel in 1¼ hours?

Ans. 40.16¼ miles.

(1124) Suppose that an air-gun can throw a ball with a velocity of 100 feet per second, and that a man standing on a railroad-train, which is moving at the rate of 100 feet per second, were to fire the gun in a direction exactly opposite to that in which the train is moving, what would become of the ball? Why?

(1125) If the distance between the center line of the handle and the axis of the drum shown in Fig. 604 is 14½ inches, and the diameter of the drum is 5 inches, what load will a force of 30 pounds exerted on the handle raise?

Ans. 174 lb.

(1126) A pulley on the main shaft is 42 inches in diameter, and makes 108 R. P. M. What will be the speed of the countershaft if the driven pulley is 36 inches in diameter? Ans. 126 R. P. M.

(1127) (*a*) What is the pitch-circle? (*b*) the pitch of a gear?

(1128) The driving gear makes 360 R. P. M., and the driven makes 170 R. P. M.; if the driver has 34 teeth, how many teeth has the driven? Ans. 72 teeth.

(1129) Name some particular use in the engine-room or shop to which you have seen the inclined plane put.

(1130) Assuming the average pressure upon the piston of a steam-engine to be 41.38 pounds per square inch, what

MECHANICS.

(PART 2.)

(1132) What is meant by the expression, *the resultant of several forces?*

(1133) If in Fig. 631 the tension in the rope is $3\frac{3}{4}$ tons, and the angle at *d* between the directions of the two parts of the rope is 30°, what is the total load on the shaft of the head-wheel?

(1134) (*a*) What do you understand by tensile strength of a material? (*b*) by working stress?

(1135) A close-link wrought-iron chain is made from $\frac{3}{8}$-inch iron; what is the greatest safe load that it will carry? Ans. 1,687.5 lb.

(1136) What is the allowable working load for a steel-wire rope $5\frac{1}{4}$ inches in circumference? Ans. 27,562.5 lb.

(1137) What steady force is required to shear a steel crank-pin which is 6 inches in diameter? Ans. 1,696,464 lb.

(1138) If a line 5 inches long represents a force of 20 pounds, (*a*) how long must the line be to represent a force of 1 pound? (*b*) of $6\frac{1}{4}$ lb.?

(1139) (*a*) What is cold-rolled shafting? (*b*) bright shafting? (*c*) black shafting?

(1140) Find the resultant of the forces acting in Fig. 805—all acting towards the same point.

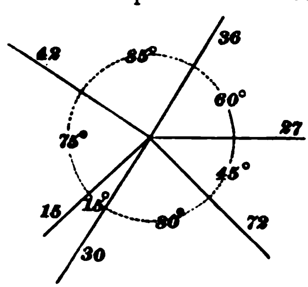


FIG. 805.

(1141) The smallest section of a connecting-rod is 3.5 square inches; what is the unit stress when subjected to a tensile stress of 12,400 pounds? Ans. 3,543 lb. per sq. in., nearly.

(1142) What load may be safely carried by a hemp rope 4 inches in circumference? Ans. 1,600 lb.

(1143) What load can be safely sustained by a round wooden pillar, 8 inches in diameter and 10 feet long, having both ends flat? 13⅓ tons.

(1144) What are the components of a force?

(1145) What should be the least diameter of a wrought-iron bolt that is to resist a sudden pull of 12,000 pounds?
Ans. 1.74 + in.

(1146) A steel-wire rope is 4¾ inches in circumference; what load will it safely sustain? Ans. 22,562.5 lb.

(1147) A white-pine beam supported at both ends has a rectangular cross-section 8 inches wide by 10 inches deep; if the beam is 28 feet long, what total uniform load will it support in safety? Ans. 6,857⅐ lb.

(1148) What horsepower can a 10-inch wrought-iron crank-shaft transmit when running at 200 revolutions per minute? Ans. 2,857⅐.

(1149) If a body be acted upon by two equal forces, one due east and the other due south, in what direction will the body move? What is the direction of the resultant of the two forces?

(1150) What should be the least area of one of the 14 wrought-iron cylinder-head stud-bolts, if the diameter of the cylinder is 19 inches, and the greatest steam-pressure is 180 pounds per square inch? Assume that the studs are subjected to shocks. Ans. .729 sq. in.

(1151) What should be the circumference of a hemp rope to safely sustain a load of 4,200 pounds? Ans. 6½ in

(1152) Regarding the connecting-rod of a steam-engine as a pillar with two round ends, what is the greatest force that may be exerted on the cross-head if the connecting-rod is made of wrought iron, is 10 feet long, and has a rectangular cross-section 6 inches by 2½ inches? Ans. 35,489 lb.

(1153) If you were to order 2½-inch bright turned shafting, what size would you expect to get?

(1154) A peg in the wall is pulled by two strings, one with a force of 21 pounds, at an angle to the vertical of 45°, and the other with a force of 28 pounds, at an angle of 60°; what is the value and direction of the resultant when the forces are on opposite sides of the vertical line? Use the method of parallelogram of forces. Ans. 30.34 lb.

(1155) A force of 87 pounds acts at an angle of 23° to the horizontal; what are its horizontal and vertical components? Find, first, by the method of triangle of forces, and, second, by trigonometry. Ans. { 33.994 lb. / 80.084 lb. }

(1156) What is the greatest safe load that may be applied to a stud-link wrought-iron chain, if the diameter of the iron from which the link is made is ½ inch? Ans. 4,500 lb.

(1157) It is desired to haul loads up to 14,000 pounds by means of an iron-wire rope; what should be its circumference? Ans. 4.83 in., nearly.

(1158) What is the greatest load that a bar of wrought iron 2 inches in diameter and 6 feet long can safely sustain in the middle? The bar is merely supported at its ends. Ans. 480 lb.

(1159) What must be the diameter of a cast-iron crank-shaft to transmit 1,000 horsepower at 80 revolutions per minute? Ans. 10.4 in.

(1160) Two forces act upon a body at a common point—one with a force of 75 pounds, and the other with a force of 40 pounds; if the angle between them is 60°, and both forces act towards the body, what is the value of the resultant? Solve by the method of triangle of forces and parallelogram of forces, and mark the direction of the resultant. Ans. 101.12 lb.

(1161) In the last example, if one force (the one of 75 pounds) acts away from the body, and the other towards it, what is the resultant? Solve by the method of triangle of forces and parallelogram of forces, and mark the direction of the resultant. Ans. 65 lb.

(1162) If two forces, of 27 pounds and 46 pounds the engine to the sheave B. The locations of the sheaves are found from the dimensions given. The resistance due to the cars and coal—that is, the tension in the rope—is 4 tons. What is the greatest pressure on the shaft of each sheave? Solve graphically by means of the parallelogram of forces.

Ans. { Pressure on sheave A, 12,400 lb., nearly.
Pressure on sheave B, 10,125 lb., nearly.

(1167) (*a*) What is a stress? (*b*) a strain? (*c*) a unit stress?

(1168) The links in a stud-link wrought-iron chain are made from iron $\frac{13}{16}$ inch in diameter; what is the greatest safe load that the chain can handle? Ans. 11,883 lb.

(1169) A steel-wire rope is used to haul cars up an inclined plane; the greatest stress in the rope is 8,000 pounds; what should its circumference be? Ans. 2.83 in.

(1170) What uniform load can be safely sustained by a steel beam 20 feet long, 2 inches wide, and 6 inches deep?
Ans. 4,608 lb.

(1171) A 4-inch steel shaft, with pulleys between bearings, is to transmit 80 horsepower; how many revolutions per minute must it make? Ans. $106\frac{1}{4}$ R. P. M.

(1172) (*a*) What is elasticity? (*b*) elastic limit? (*c*) What is meant by set?

(1173) What safe load may be carried by a close-link wrought-iron chain whose links are made from $\frac{5}{8}$-inch iron?
Ans. 4,687.5 lb.

(1174) What is the allowable working load for an iron-wire rope 6 inches in circumference? Ans. 21,600 lb.

(1175) What force is required to shear a wrought-iron strip 4 feet long and $\frac{1}{2}$ inch thick? Ans. 960,000 lb.

(1176) A 7-inch wrought-iron crank-shaft is to transmit 200 horsepower; how many revolutions per minute must it make? Ans. 40.8 rev., nearly.

(1177) What force is required to punch a 1-inch hole through a wrought-iron plate $\frac{7}{16}$ inch thick? Ans. 54,978 lb.

(1178) What horsepower will a $1\frac{1}{8}$-inch wrought-iron

STEAM AND STEAM-BOILERS.

(1188) (*a*) What is heat? (*b*) Suppose a closed vessel containing air is placed in a furnace; describe the effect of the heat upon the molecules of the air. (*c*) If the vessel is so arranged that the air can not escape or expand, will the pressure of the air increase as it is heated? (*d*) Why?

(1189) (*a*) What is temperature? (*b*) Describe the thermometer. (*c*) Of what is temperature a measure?

(1190) A bar of iron weighing 2½ pounds has a temperature of 460°. Does the bar contain more or less heat than 10 pounds of water at 60°?

(1191) (*a*) What are some of the effects of heat? (*b*) Give some practical illustrations of the expansion of bodies by heat.

(1192) (*a*) What is a B. T. U.? (*b*) What is latent heat? (*c*) What is sensible heat? (*d*) What is meant by the specific heat of a substance?

(1193) A pound of ice at 16° is heated until it finally is changed to steam at atmospheric pressure. (*a*) Describe the action of the heat upon the ice and water. (*b*) How many B. T. U. are required for the operation? (*c*) What part of the heat applied is sensible heat? (*d*) What part is latent heat?

(1194) (*a*) What is the mechanical equivalent of heat? (*b*) Give examples of heat changed to work, and *vice versa*. (*c*) How many foot-pounds of work are equivalent to 30½ B. T. U.? Ans. (*c*) 23,729 ft.-lb.

(1195) Assuming 20% of the heat to be utilized, how

(1218) If we have 5 cubic feet of saturated steam in a cylinder at 60 pounds pressure above a vacuum, what will be its pressure after it has expanded to 2.5 times its original volume, assuming the expansion to follow Mariotte's law?

Ans. 9.3 pounds per square inch above the atmospheric pressure.

(1219) If 11 pounds of coal are burned per square foot of grate surface per hour in a furnace having a grate area of 13 square feet, how many B. T. U. will be generated in 5 hours, if the combustion of the coal is complete?

Ans. 10,105,095 B. T. U.

(1220) How much air would have to be supplied to promote the complete combustion of the coal in Question 1219, if the furnace is operated under a blast draft?

Ans. 10,010 lb.

(1221) What is the equivalent of the heat of combustion of the fuel in Question 1219, expressed in pounds of water evaporated from 62° F. and at 212° F.?

Ans. 9,059.05 lb. of water.

(1222) The pressure in a boiler is 3,600 pounds per square foot above a vacuum; what is the pressure in the boiler measured in pounds per square inch above the atmospheric pressure? Ans. 10.3 lb. per sq. in.

(1223) Does saturated steam contain the same amount of heat per unit of weight at all pressures?

(1224) If a vertical boiler were generating steam at a gauge-pressure of 152 pounds per square inch, what would be the temperature of the water in the boiler?

Ans. 371.62° F.

(1225) On placing a thermometer in a jet of steam issuing from a blow-off pipe, we find its temperature to be 232° F.; what is the pressure behind the steam?

Ans. 5.57 lb. per sq. in. gauge-pressure.

(1226) If a coal-mine having a shaft 296 feet deep has an output of 132 tons of coal per hour, how many of the British forced or blast draft? What advantage has the latter over the former?

(1234) What means are usually supplied to facilitate the cleaning of boilers?

(1235) Why are steam-gauges a necessary part of every boiler?

(1236) Why should the water in a boiler be prevented from getting low while the furnace is in full operation?

(1237) Why are internally fired boilers usually bricked in?

(1238) How is the masonry work about a boiler usually strengthened?

(1239) Where should firebrick be used when setting a boiler?

(1240) Describe three different kinds of grates with which you are familiar.

(1241) What is a steam-pipe? a feed-water pipe? a blow-off pipe?

(1242) What are safety-valves? Describe the principle upon which they are operated.

(1243) How far must a 54-pound weight be placed from the fulcrum of a safety-valve that has an area of 6 square inches and is 2 inches from its fulcrum, if the valve is to blow off at 81 pounds per square inch? Ans. 18 in.

(1244) The shell of a plain cylindrical boiler is 30 inches in diameter and 20 feet long, and is made of single-riveted wrought-iron boiler-plate $\frac{3}{8}$ of an inch thick; what is the greatest boiler-pressure under which it can be safely operated? Ans. 127.8 lb. per sq. in.

(1245) (a) What is meant by the horsepower of a boiler? (b) What is the standard horsepower?

(1246) (a) What is meant by the term *heating-surface?* (b) What portions of an ordinary vertical boiler are heating-surface?

the cards shown in Figs. 807, 808 and 809, 810 were taken, what would have been the effect upon the back-pressure line of the cards?

(1289) How are hoisting and tail-rope haulage-engines governed?

(1290) What is meant by *clearance* of a steam-cylinder?

(1291) How is motion imparted to the slide-valve?

(1292) During the period of expansion in the crank end of the cylinder, what occurs in the head end of the cylinder?

(1293) What does the compression-curve show?

(1294) In what direction should the fly-wheel be rotated when setting a plain slide-valve?

(1295) What is meant by a *40-pound*, a *20-pound*, or a *75-pound* indicator-spring?

(1296) What is the scale of an indicator-spring?

(1297) What is the advantage of using the condensed steam from a condenser, as boiler feed-water?

(1298) What outlet is provided in steam-cylinders for the discharge of water that may accumulate as the result of the condensation of steam?

(1299) What is the angle between the crank and eccentric?

(1300) If a valve has a slight lead, does the point of admission occur at the beginning or end of the stroke?

(1301) What conditions must be fulfilled in setting a plain slide-valve?

(1302) Why is it necessary to employ a reducing motion in connection with an indicator?

(1303) If a non-condensing engine is working under a boiler-pressure of 75 pounds per square inch, what is the approximate M. E. P. if the engine cuts off at $\frac{3}{10}$ stroke? at $\frac{1}{2}$ stroke?

Ans. 41.86 and 53.16 lb. per sq. in., respectively.

(1304) What is the principle that insures the action of steam-engine governors?

(1351) Four cubic feet of air are heated under a constant pressure from 40° to 115°. What is the resulting volume?
Ans. 4.6012 cu. ft.

(1352) State the advantages of cooling air during compression; of reheating it.

(1353) What are the absolute temperatures corresponding to 32°, 212°, 62°, 0°, and −40°?

(1354) Three and one-half pounds of air under a pressure of 10 atmospheres occupy a volume of 4 cubic feet; what is the temperature? Ans. −5.583°.

(1355) State some of the disadvantages of the duplex type of air-compressor.

(1356) 11.798 cubic feet of air are under a pressure of 130 pounds per square inch. If the pressure is lessened until the volume is 75 cubic feet, what is the resulting tension? Ans. 20.45 lb. per sq. in.

(1357) What is the temperature of 14 cubic feet of air having a tension of 18 pounds per square inch and weighing 1.2 pounds? Ans. 107.77°.

(1358) Twenty-one cubic feet of air are heated from 60° to 420°; what is the new volume? Ans. 35.57 cu. ft.

(1359) If 12 cubic feet of air have a temperature of 90° and a tension of 6 atmospheres gauge, what is the weight of 1 cubic foot? Ans. .50586 lb.

(1360) A vessel containing 3 cubic feet of air, weighing .5 pound under a pressure of one atmosphere, has compressed into it enough more of the air to make it weigh 1 pound and 6 ounces; the temperature remaining the same, what is the new tension of the air in pounds per square inch?
Ans. 40.425 lb. per sq. in.

(1361) If 4,516 cubic inches of gas having a temperature of 260° are cooled down to a temperature of 80°, the pressure remaining the same, what is the new volume?
Ans. 1.96 cu. ft.

of mercury; what is the equivalent pressure upon a square foot? Ans. 1.764 lb.

(1372) What is a *partial vacuum?* If enough air is admitted to the vacuum-chamber to cause the column of mercury to be 4½ inches shorter than the barometer column, how many inches of vacuum will the gauge show?

Ans. 25½ in.

(1373) A vacuum of 27 inches will support a column of water of what height? Ans. 30.6 ft.

(1374) What is the purpose of a pressure-regulator? Describe its action.

(1375) What is the office of the receiver? What should be the volume of a receiver which supplies air to 8 rock-drills?

(1376) What is meant by the *efficiency* of an air-compressor? State fully the losses which may occur when compressed air is used. What means should be adopted to reduce these losses as far as possible?

edge of which measures 10½ inches, if sunk 3½ miles below sea-level?

(1407) The diameter of the bottom of a pail is 8 inches, and the height of the contained water is 12 inches; (*a*) what is the total pressure on the bottom of the pail? (*b*) What is the pressure per square inch?

Ans. { (*a*) 21.82 lb.
(*b*) .434 lb. per sq. in.

(1408) What must be the diameter of a pump-plunger to throw 8,000 gallons per hour, the length of the stroke being 10 feet, and the number of strokes per minute 7? Ans. 7⅝ in.

(1409) What are the advantages of the pulsometer?

(1410) If a suction-pump lifts water 25.5 feet near the sea-level, where the height of the mercury column is 30 inches, how high will the same pump lift water on the top of a mountain, where the mercury stands at 22 inches?

Ans. 18.7 ft.

(1411) A dam is 40 feet long and 12 feet high; what is the total pressure on the dam? Assume that a cubic foot of water weighs 62½ pounds. Ans. 180,000 lb.

(1412) Calculate the diameters of the plunger, of the suction-pipe, and of the delivery-pipe for a double-acting pump throwing 750 gallons per minute. Assume 100 feet per minute as piston speed.

Ans. { Plunger, 15 in.
Delivery, 7 in.
Suction, 10 in.

(1413) The total length of a siphon is 840 feet, the head is 40 feet, and the diameter 6 inches; what is the discharge in gallons per hour? Ans. 44,553.6 gal. per hr.

(1414) The lever of a hydraulic press is 7½ feet long, the piston-rod being 1 foot from the fulcrum. The area of the tube is ½ a square inch; that of the cylinder 80 square inches. What weight may be raised by a force of 80 pounds applied at the end of the lever? Ans. 96,000 lb.

(1415) A duplex electric sinking-pump lifts 200 gallons

(1430) In Fig. 736 the weight on piston *a* is 22 pounds; the area of *a* is 5 square inches, and the area of *b* is 73 square inches; what must be the weight on *b* to just balance the weight on *a*? Ans. 321.2 lb.

(1431) Why can water be sucked up through a straw?

(1432) The diameter of the water-cylinder of a single direct-acting pump is 11 inches. The steam-pressure is 50 pounds per square inch, and the height of the lift is 300 feet; (*a*) find the discharge per hour. (*b*) Find the diameter of the steam-piston. (*c*) What is the horsepower of the pump? Assume the piston speed as 100 feet per minute.

Ans. { (*a*) 23,696.64 gal. per hr.
(*b*) $19\frac{1}{2}$ in.
(*c*) 45.024 H. P.

(1433) If a piece of glass be laid upon a flat surface which has been moistened, it will require considerable exertion to separate them. Why?

(1434) The total length of a siphon is 88 feet; the head is 15 feet, and the diameter $3\frac{1}{2}$ inches; what is the discharge in gallons per minute? Ans. 342.66 gal. per min.

(1435) What should be the size and proportions of a direct-acting steam-pump to deliver 18,000 gallons per hour against a head of 225 feet? Assume the average steam-pressure to be 50 pounds per square inch. Add one-half to the indicated horsepower for friction, etc., and take the piston speed as 110 feet per minute.

Ans. { Diameter of steam-cylinder, 14 in.
Diameter of water-cylinder, $9\frac{1}{8}$ in.
Stroke, 12 in.
Diameter of suction-pipe, 6 in.
Diameter of discharge-pipe, $4\frac{1}{2}$ in.

(1436) The area of the cross-section of an orifice in a thin plate is 11.2 square inches. There being a constant head of 15 feet 9 inches, (*a*) what is the theoretical discharge in cubic feet per minute? (*b*) What is the actual discharge in cubic feet per minute?

Ans. { (*a*) 148.54 cu. ft. per min.
(*b*) 91.344 cu. ft. per min.

(1437) Why must a siphon be filled with water, or have the air exhausted from it, before it will work?

(1438) The diameter of the plunger of a pump is 19 inches; the length of the stroke is 9 feet, and the number of strokes per minute 5; (*a*) what is the discharge in gallons per minute? (*b*) per hour? Calculate the discharge by formula **191.**

Ans. { (*a*) 530.24 gal. per min.
(*b*) 31,814.4 gal. per hr.

(1439) A pumping-engine lifts 80,000 gallons per hour 340 feet, with a coal consumption of 400 pounds; what is the duty? Ans. 56,814,000 ft.-lb.

(1440) Find the heads of water corresponding to the following pressures: (*a*) 80 pounds per square inch; (*b*) 30.5 pounds per square inch; (*c*) 108 pounds per square inch; (*d*) 215 pounds per square inch.

Ans. { (*a*) 184.32 ft.
(*b*) 70.272 ft.
(*c*) 248.832 ft.
(*d*) 495.36 ft.

(1441) The piston speed of a duplex steam-pump is 100 feet per minute; the diameter of the plunger is 14 inches; what is the delivery in gallons per hour?

Ans. 76,769.28 gal. per hr.

(1442) A 4-inch pipe 5,000 feet long is required to deliver water with a velocity of 8 feet per second; what must be the head? Ans. 307.46 ft.

(1443) A cylindrical vessel, 3 feet in diameter and 12 feet long, is placed upon one end, so that its axis is vertical. Suppose that it is kept filled with water which flows through a hole in the bottom; what will be the velocity of efflux if the hole is 11 inches square? Ans. 27.979 ft. per sec.

(1444) A compound condensing pumping-engine delivers

4,000,000 gallons of water in 10 hours, against a head of 125 feet. The number of pounds of coal burned in 10 hours is 7,460; what is the duty? Ans. 55,998,660 ft.-lb.

(1445) A Cornish pumping-engine has a stroke of 10 feet. The pit-work weighs 20 tons, the water-column 12 tons, and the frictional resistances are 3 tons; what must be the weight of the counterbalance in order that the greatest speed of the pit-work may be about 200 feet per minute? Ans. 2.6 tons.

(1446) How is the expansion of steam obtained in a compound pumping-engine?

(1447) State some of the advantages of using an electric sinking-pump.

(1448) What should be the diameters of (*a*) the suction and (*b*) delivery pipes of a pump which discharges 70,000 gallons of water per hour? Ans. { (*a*) 12 in. (*b*) $8\frac{1}{2}$ in.

(1449) What must be the horsepower of a pump to deliver 100,000 gallons of water per hour against a head of 480 feet? Ans. 304 H. P.

(1450) How many gallons per hour will a 7-inch pipe deliver, if the mean velocity of the water at the point of efflux is 7.21 feet per second? Ans. 51,891.24 gal. per hr.

(1451) What special advantages does the Cameron sinking-pump possess over other steam sinking-pumps?

(1452) In what cases can a hydraulic pump be used to a great advantage?

(1453) State what is meant by a Cornish pumping-engine; a Bull engine; a sinking-pump; a hydraulic engine; a siphon.

(1454) What is the usual practice in regard to the velocity of the water in the suction-pipe? in the delivery-pipe? What is the usual limit of piston speed in pumps?

(1455) How many gallons of water will a pump deliver